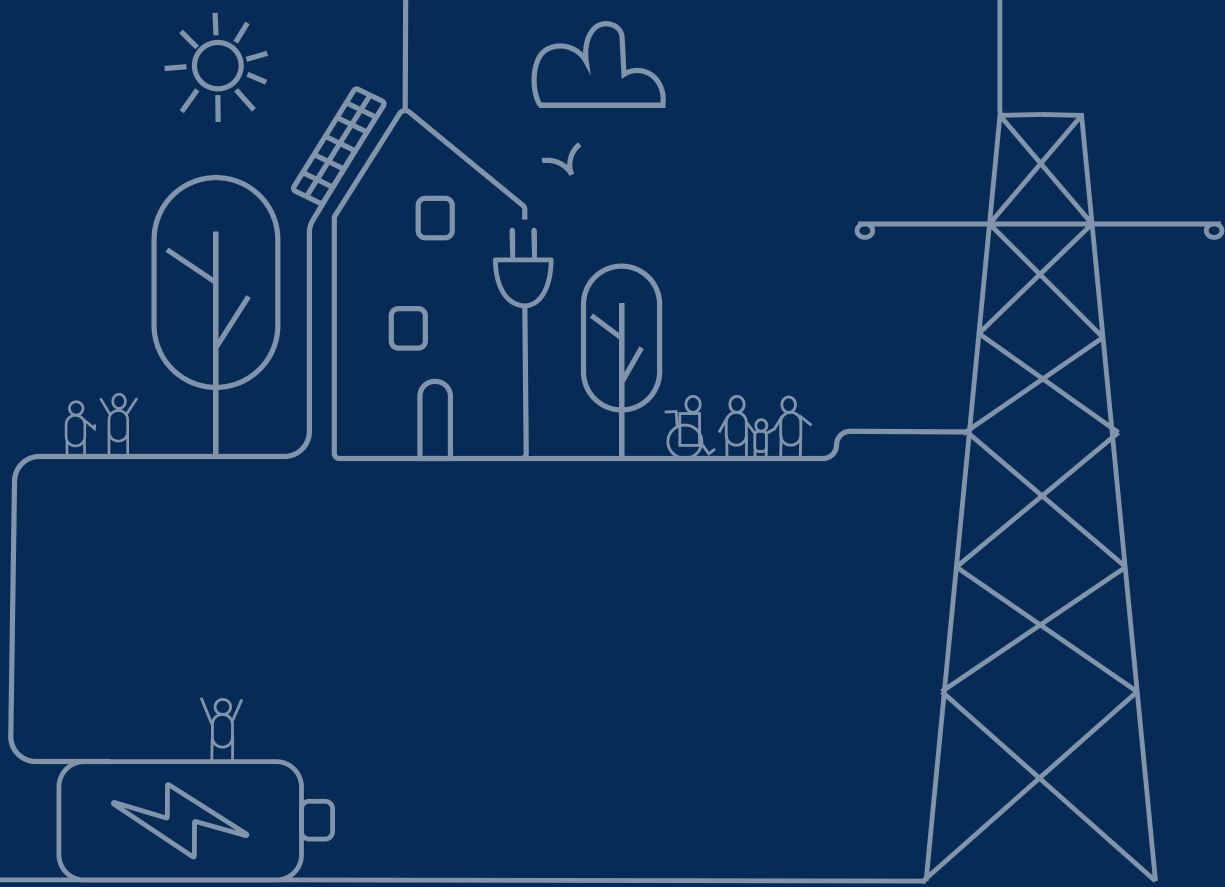
From design to reality:

Long term performance of new build, low-carbon affordable homes



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Authors

- **Professor Joanne Patterson**, Principal Investigator
- **Dr Emmanouil Perisoglou**, Co-Investigator
- **Miltiadis Ionas**, Research Assistant

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More Homes Team

- **Carol Morgan**, Head of Housing and Public Health
- **Rosie Jackson**, Housing Strategy and Development Manager
- **Tim Padfield**, More Homes Development Officer
- **Matthew Williams**, More Homes Development Officer

Mechanical design and maintenance team

- **Scott Jewell**, Senior Mechanical Maintenance Manager
- **Tim Shaw**, Mechanical Engineer
- **James Horner**, Mechanical Engineer

Electrical design and maintenance team

- **Jonathan Davies**, Senior Electrical Installations and Maintenance Manager
- **Matt Davies**, Electrical Engineer

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Foreword

As Deputy Leader of Swansea Council, I am proud to introduce this important report showcasing the real-world performance of our new generation of affordable, low-carbon homes. The findings presented here by the Welsh School of Architecture, Cardiff University provide clear and independent evidence that our approach is working: our homes are warmer, healthier, more comfortable and significantly cheaper for residents to run.

At a time when many households are feeling the pressures of rising living costs, this work demonstrates what is possible when innovation, strong partnerships and a shared commitment to tackling fuel poverty come together. Swansea's 'Swansea Standard' homes are already helping families save hundreds of pounds a year on their energy bills while reducing carbon emissions and contributing to our wider climate goals.

I would also like to express our thanks to the Welsh Government for their continued funding support, which has been vital in enabling us to deliver these exemplary low-carbon homes and to push forward with our ambition for a fairer, greener Swansea.

This report also highlights something equally important: that good design is not just about buildings, it is about people. The insights gained through monitoring and resident feedback will help us continue improving how we support tenants, simplify controls, and make sure our homes work for everyone.

I want to thank the Centre for a Low Carbon Built Environment at the Welsh School of Architecture at Cardiff University for their rigorous research and all Swansea Council staff, partners, and residents who contributed to this work. Together, we are demonstrating that affordable, sustainable housing is not only achievable but essential, and that Swansea is leading the way in delivering the homes of the future.

Cllr Andrea Williams
Deputy Leader, Swansea Council

1 Report summary

Housing demand has steadily increased across the Swansea Council (SC) area since 2016, with a more rapid increase since 2020 due to the impact of the COVID pandemic, the cost-of-living crisis, energy price rises and a general lack of affordable housing. SC resumed their new home building programme in 2015, with the design and build of 18 homes in the Penlan area of the city which included a mix of flats and houses following the Passivhaus approach. In 2019, SC launched 'More Homes', a 10-year Programme focussing on increasing the amount of affordable housing across the County. 'More Homes' aims to provide 1,000 additional SC owned homes between 2021–2031 through the purchase of existing housing across the area, the conversion of other building types to housing and through planning, designing and building new SC owned homes.

Moving away from Passivhaus, the 'More Homes' Programme [1] takes a whole-house energy systems approach to new build housing, informed through the monitoring and evaluation of the Passivhaus development and evidence from the Welsh School of Architectures (WSA) energy positive 'Solcer' House [2]. The whole-house 'Swansea Standard' energy system approach complies with Welsh Government funding requirements for Social Housing Grants including the Welsh Development Quality Requirements (WDQR21) for all new social housing, working towards net-zero carbon [3]. WDQR21 homes should achieve an EPC rating of A, meet space standards and safety and security requirements and should not include fossil fuel fired boilers for domestic hot water and heating.

Between 2021–2025 the Centre for a Low-Carbon Built Environment (CLCBE), at the Welsh School of Architecture (WSA), Cardiff University (CU) monitored and evaluated 65 'Swansea Standard' new-build homes – 39 houses, 20 flats and 6 bungalows – located across four sites throughout the County for up to 3 years each.

Each of the 65 new build 'Swansea Standard' homes have:

- High levels of insulation and high-performance windows and doors.
- A heat pump to provide space heating and hot water.
- Mechanical Ventilation with Heat Recovery (MVHR).
- Building-integrated photovoltaic (BIPV) systems.
- A battery to store energy.

This report presents the method and results of the monitoring and evaluation. It is designed to be practical and useful for people involved in the housing sector – local authorities, Registered Social Landlords, residents, developers, supply chains and National Government. By sharing real-world experiences from planning, design, procurement, construction and maintenance and operation, more low-carbon affordable new housing can be built.

1.1 Key outcomes

Evidence gathered through monitoring and evaluation has helped to understand the amount of energy consumed within the homes, the quality of the build, the performance of the low-carbon solutions and the experience and satisfaction of the residents. Key outcomes are:

- Average annual energy use of the homes across the four sites was 58 kWh per m^2. This is about three times lower than the average for similar housing stock and two times lower than the SAP new buildings minimum requirement at the time of design. It is also comparable to future targets such as the 2025 RIBA target [4, 5]. Comparisons with business as usual, and current, and future targets are shown in Figure 1.
- On average 47% of the energy used (28 kWh/m^2 year) within the homes came from on-site renewable sources – either directly from the building integrated solar PV panels or via battery storage, while the other 53% (30 kWh/m^2 year) was imported from the electricity grid.
- Surplus energy from the building integrated solar PV panels was generated – on average 15 kWh/m^2 year is available for export back to the grid.
- Indoor temperatures stayed within a comfortable range [6] across the homes for 78% of the time, humidity levels were within recommended limits [7] 93% of the time and CO_2 concentration levels met good air quality Standards [8] for 96% of the time.
- 79% of residents confirmed that they felt their energy bills were either affordable or reasonable.
- Survey responses showed 100% satisfaction with overall living experience in the homes.

Figure 2 highlights further outcomes from the monitoring and evaluation including energy use, resident comfort and satisfaction.

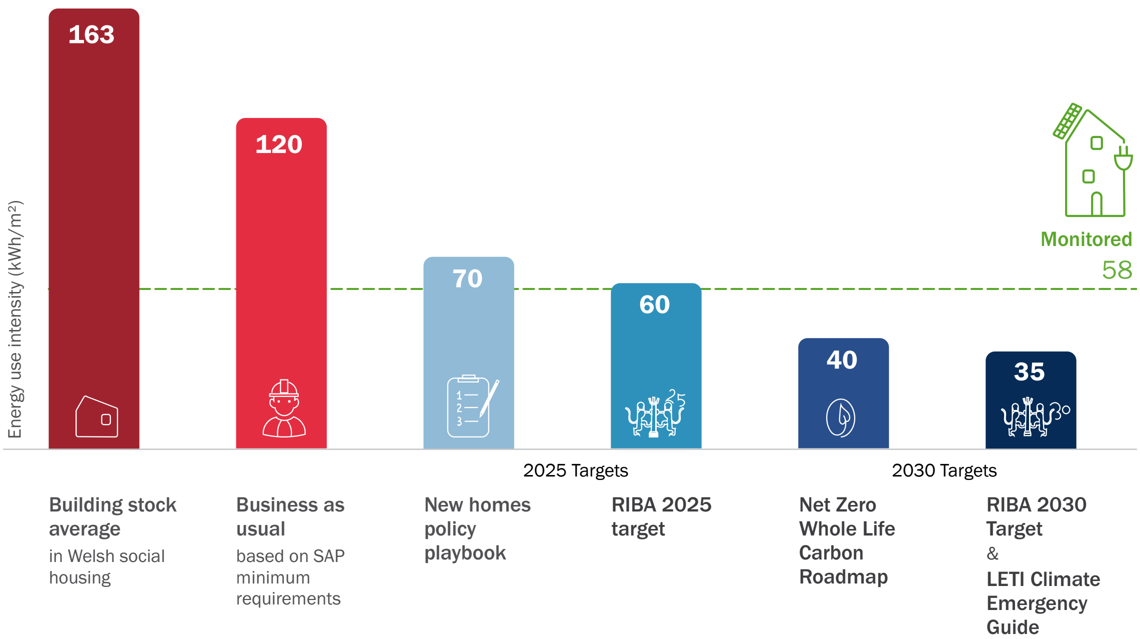


Figure 1: Annual Home Energy Use Intensity (EUI) against benchmarks and targets [4, 5, 9, 10, 11]

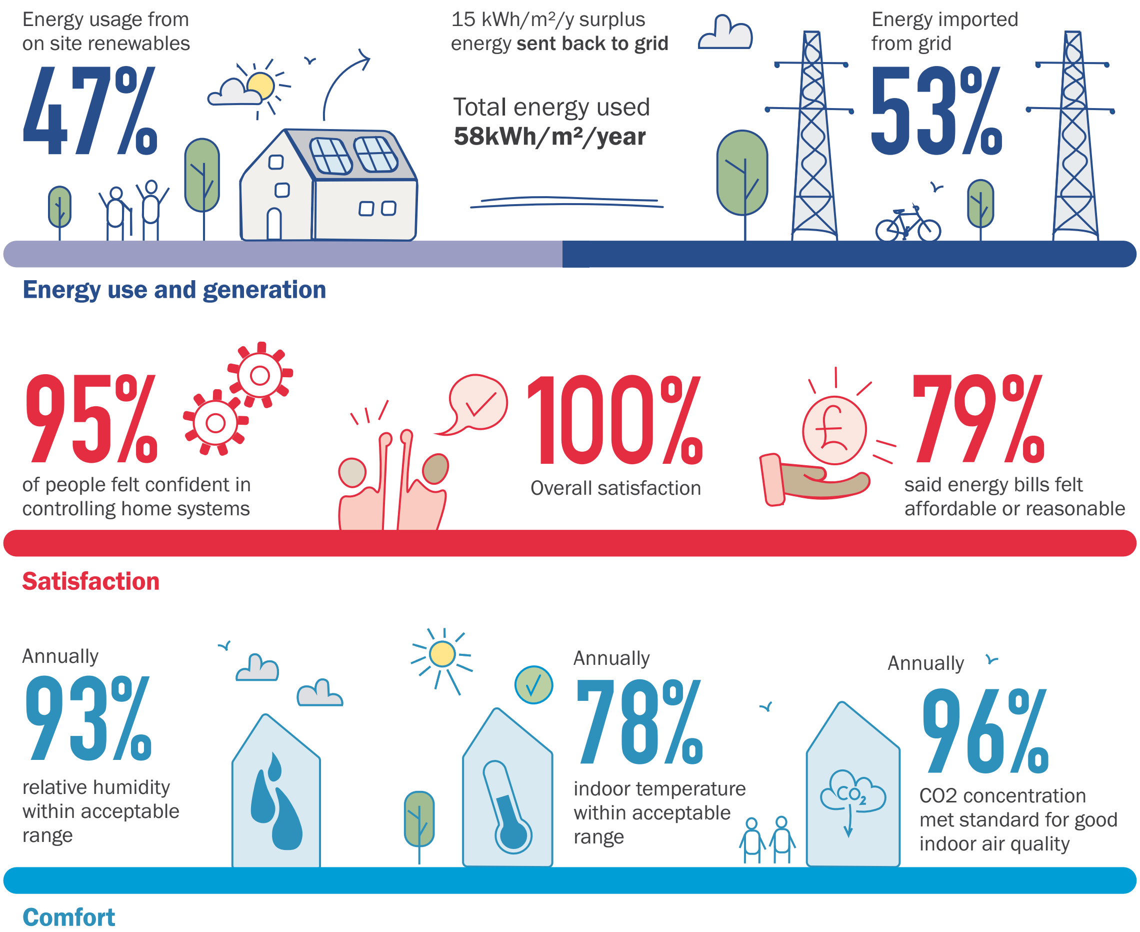


Figure 2: Outcomes associated with energy use and generation, resident satisfaction and comfort

1.2 Key insights

Monitoring and evaluation key insights are provided to help inform future decision making:

1. Data and Information

Combining long-term building, technology and systems monitoring and evaluation with resident questionnaires and interview enhances the value of the data collected. For example, CO_2 concentrations met good air quality standards 97% of the time, confirmed with positive responses from residents regarding air quality. High quality, reliable data can reinforce confidence in design strategies and guide targeted improvements.

2. Technical

Homes achieved an average Energy Usage Intensity (EUI) of 58 kWh/m²/year, well below the national average for similar size new-build homes. This demonstrates that technical performance, when supported by appropriate commissioning and controls, aligns closely with design targets. Taking a whole-house energy system approach has proved effective in reducing energy use and therefore CO_2 emissions, minimising energy bills and providing a comfortable and healthy internal environment.

3. Supply chains

Defining quality standards from the outset and enabling collaborative communication across the supply chain, including suppliers and contractors throughout the construction process, ensured design targets, such as airtightness – below 5 $m^3/h/m^2$ @ 50Pa – were consistently met.

4. Skills

Enhanced system performance was a focus for skill development and training during the installation and commissioning of technologies. For example, where MVHR systems were re-commissioned or where staff had deeper understanding of heat pump settings, better indoor air quality and comfort were achieved with operational energy and cost reductions.

5. Occupants and behaviour change

Resident knowledge plays a critical role in how effectively homes and the systems perform. When residents are well-informed and supported over time, use matches design performance. For example, where residents were engaged in communications, indoor temperatures remained within the comfort range for 78% of the year and optimal humidity levels for 93% of the time.

6. Financial and monetary

Residents were financially better off as a result of energy use reductions. On-site renewables contributed an average of 28 $kWh/m^2/year$ reducing grid dependency by almost half. This helped residents to reduce energy costs, evidenced by 80% reporting that bills were manageable or cheap.

7. Collaboration and decision making

Collaboration and communication between researchers, council staff and residents enabled responsive decision-making throughout the project led to improved performance. For example, overheating issues were addressed efficiently through joint site visits resulting rapid response to issues.

8. Policy, regulation and standards

The 'Swansea Standard' approach outperformed Building Regulation targets and aligned closely with Passivhaus U-values (0.14 W/m^2K). This demonstrates how voluntary, evidence-led innovation can drive the development of net-zero housing that is ready for future generations.

2 Introduction

New-build homes in the UK are increasingly being designed to be low or net-zero carbon in line with national net-zero targets. In 2015, the Paris Agreement, a legally binding international treaty on climate change, was signed by 195 countries from across the globe to pursue efforts "to limit the temperature increase to 1.5 °C above pre-industrial levels" in an attempt to limit frequent and severe droughts, heatwaves and increased rainfall [12]. The UK government committed to reaching net-zero greenhouse gas emissions by 2050, with housing being a key part of this transition [13].

To support this goal, regulations and standards associated with housing are changing, to encourage change and innovation, not only through technology, but through processes and ways of working through collaboration to support scale-up. In 2023, the Welsh Housing Quality Standard [14] was updated to include an emphasis on decarbonisation and energy efficiency to reduce carbon emissions and lower energy costs for residents . Delivering very low or net-zero carbon homes will ensure compliance with future regulations, reducing long-term energy costs for residents, therefore reducing fuel poverty whilst contributing UK efforts to mitigate climate change.

2.1 Development of the 'Swansea Standard'

In 2015, after a gap of 40 years, SC resumed building new homes for rent. A development of 18 homes built to Passivhaus standards was commissioned, working with an independent architectural practice. The development in the Penlan area of the city comprised of 1 and 2 bed flats and houses, where the need for space heating was reduced through increased insulation and minimising points of heat loss. SC invited the WSA team to monitor these homes between 2017 – 2020 to evaluate performance and help inform future housing design.

The collaboration between SC and the WSA team was initiated during a visit to the 'Solcer' House, an innovative energy-positive affordable home designed and built by the CLCBE team in 2014–2015 [2]. The 'Solcer' House demonstrated a whole-house energy system approach to design, including reduced energy demand through optimising insulation levels combined with low energy technologies such as an exhaust heat pump and ventilation alongside renewable energy generation such as solar photovoltaic panels and battery storage. Extensive modelling and monitoring of the 'Solcer' House saw carbon emissions reduced by over 80%, lower energy bills and therefore reduced fuel poverty whilst providing a comfortable, attractive and affordable place to live.

Funded through the Wales European Funding Office (WEFO) SPECIFIC Programme, SC and CLCBE applied the whole-house energy system approach together to retrofit 6 bungalows in a semi-urban location in Swansea County [15]. Working closely through all stages from planning, design, procurement, construction and maintenance and operation, all stakeholders including residents, the supply chain and District System Operator (DSO) were engaged throughout. This multi-award-winning innovative project enabled carbon emissions to be reduced by 99%, energy bills reduced by 80% and resident comfort significantly improved.

A positive collaborative working relationship is well established between SC and the CLCBE team. SC bring hands-on experience managing and delivering social housing improvements, with CLCBE team bringing experience and ability to carry out research that provides evidence on the integration of low-carbon solutions into buildings.

As a result of these experiences, SC developed the 'Swansea Standard' bringing together lessons from the Passivhaus development, the 'Solcer' House and the retrofit project to align with the Welsh Housing Quality Standard (WHQS). This whole-house energy system-based approach aims to exceed Building Regulations by at least 25%, through using high-performance materials, optimising air tightness and ventilation whilst incorporating renewable energy and storage where appropriate. SC aim to provide low-carbon affordable homes that are cheaper to run and comfortable for residents.

Between 2021 and 2023, SC built 65 'Swansea Standard' homes across four sites across the County. The WSA CLCBE team were commissioned to monitor and evaluate these homes to provide evidence on how well they performed in the real-world, helping to inform future housing policy and design. Figure 3 illustrates the SC and WSA/CLCBE collaboration timeline.

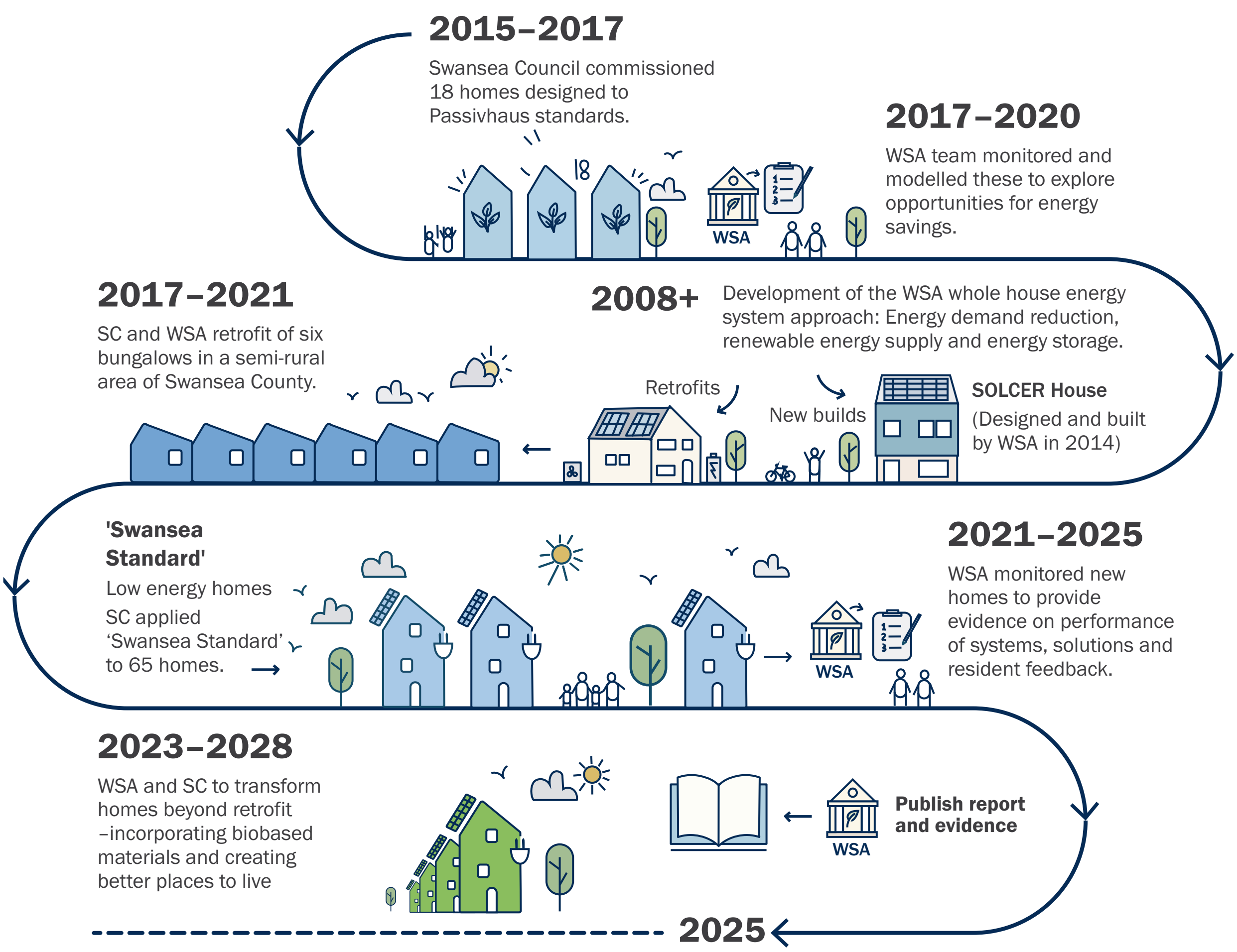


Figure 3: Swansea Council and Welsh School of Architecture, Cardiff University collaboration timeline

2.2 Monitoring and evaluating the 'Swansea Standard'

The 65 'Swansea Standard' homes, designed and built by SC include 20 flats, 39 houses and 6 bungalows located across four sites. The CLCBE team worked with SC to design a monitoring and evaluation approach that would help to understand how the homes perform in the real-world. Monitoring and evaluation focused on measuring energy use, assessing the performance of individual solutions and the system as a whole whilst understanding residents' comfort, experience and satisfaction.

Information gathered meant that issues could be rectified in the short term so that the performance of the homes built could be improved, whilst feeding into future developments.

2.3 The 'Swansea Standard' homes

The four sites are located in suburban areas across the county. Figure 4 summarises the number of homes and housing types. The homes are on the electricity grid only, with no gas supply.

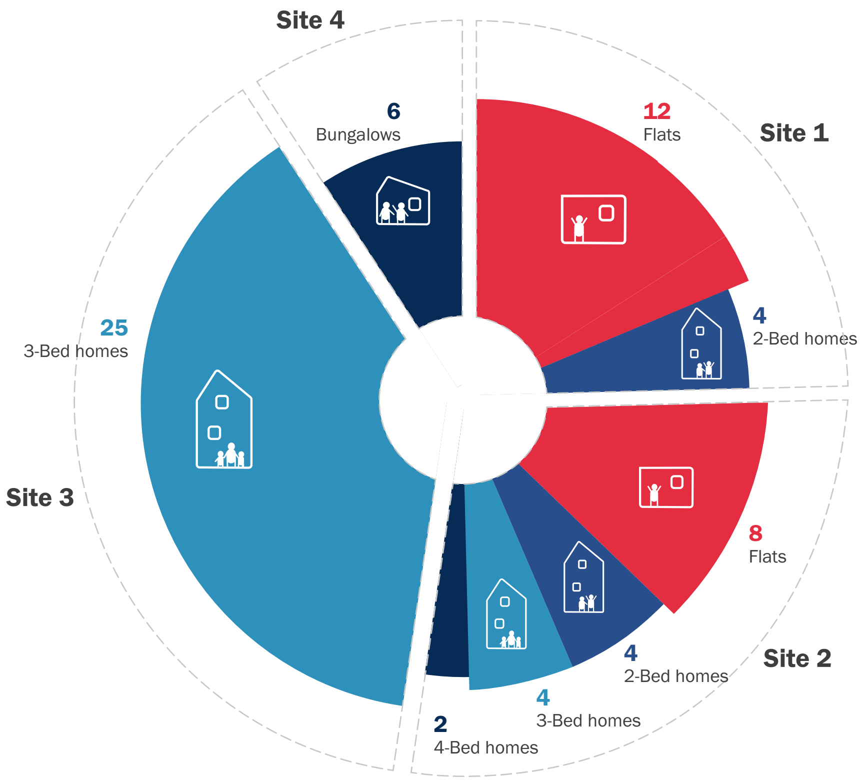


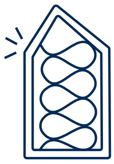
Figure 4: Number and type of homes located across four sites

All four sites are flat and are not shaded by adjacent trees, buildings or infrastructure. Figure 5 presents the layout of the four sites and the housing orientation. Orientation can impact on energy performance including how much sunlight is received which influences how much renewable energy is generated, how much energy is needed for lighting and the level of natural heat gained. This can impact indoor temperatures and therefore comfort. Images of the housing types and styles are presented in Figure 6.

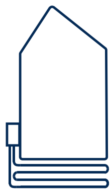
Figure 5: Layout and orientation of new-build housing across the four sites

Figure 6: Images of new-build homes across four sites

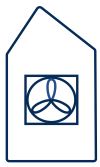
The low-carbon features specified for the ‘Swansea Standard’ design include high performance fabric and a combination of low-carbon technologies as illustrated in Figure 7.



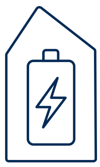
High levels of **insulation** and **high-performance** windows and doors – target **air tightness permeability** lower than 5 m³/h·m² s@50 Pa.



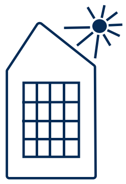
Ground-Source Heat Pump (**GSHP**) to provide **low-carbon space heating** and **domestic hot water** at 3-6 kW.



Mechanical Ventilation with Heat Recovery (**MVHR**) to **recover heat** and provide **clean air** to living spaces.



Battery storage system with a storage capacity 13.5 kWh and rate at 5 kWp.



Building-integrated **photovoltaic (BIPV)** systems from 4.0–4.5 kWp.

Figure 7: A summary of ‘Swansea Standard’ approach across the four sites.

‘Swansea Standard’ fabric

Building fabric included highly insulated walls and loft to Passivhaus Standard. Sealing and construction detailing was used to optimise airtightness and thermal bridging. These are illustrated in Figure 8. Solar gains are optimised using high window to wall ratios according to facade orientation.

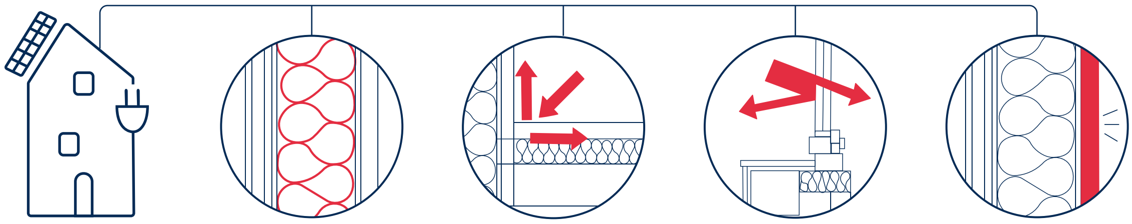


Figure 8: The ‘Swansea Standard’ fabric approach

U-values are used to compare performance of different wall compositions – a lower U-value represents lower heat loss. Prior to 2022 (and when SC homes were designed), the maximum U-value set by Welsh Building Regulations was 0.30 W/m²/K with a suggested target of 0.18 W/m²/K. These targets changed in Wales in 2022 with a target U-value set at 0.18 W/m²/K for homes with 0.21 W/m²/K for flats is permitted. The combination of applied for the wall make up in the ‘Swansea Standard’ homes (Figure 9), enables a U-value of 0.14 W/m²/K to be achieved.

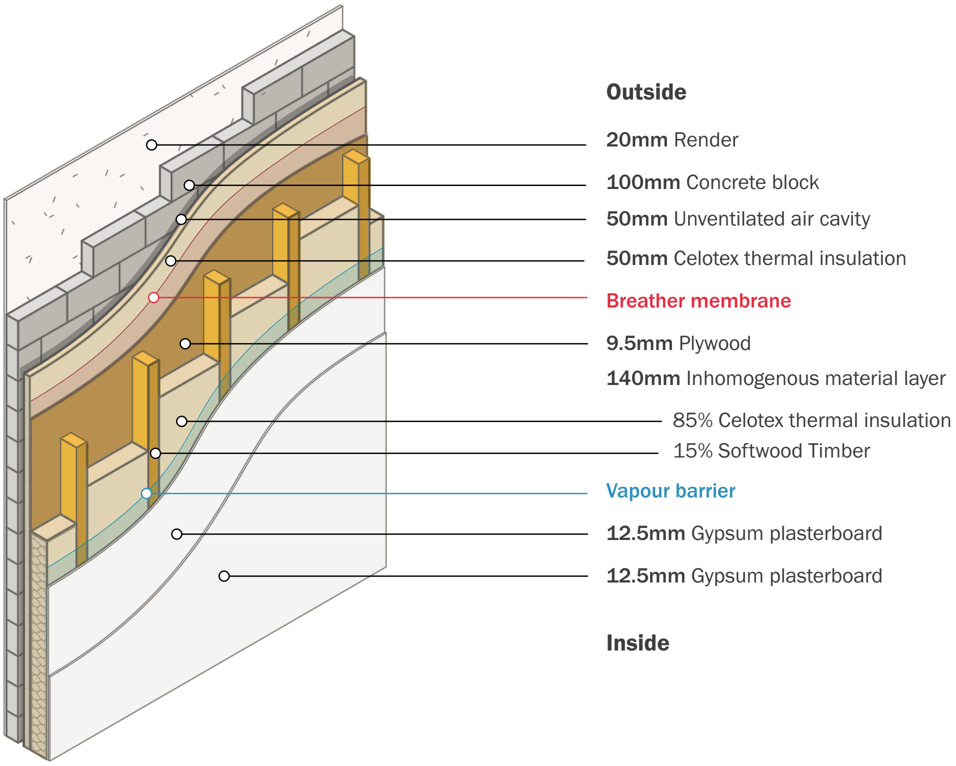


Figure 9: External wall make-up illustrating level of insulation for ‘Swansea Standard’ Homes

Figure 10 illustrates the reduction in Building Regulation U-value targets since 2016 [16], as well as the Passivhaus standard for cooler climates [17]. The ‘Swansea Standard’ design target aimed for better than Passivhaus.

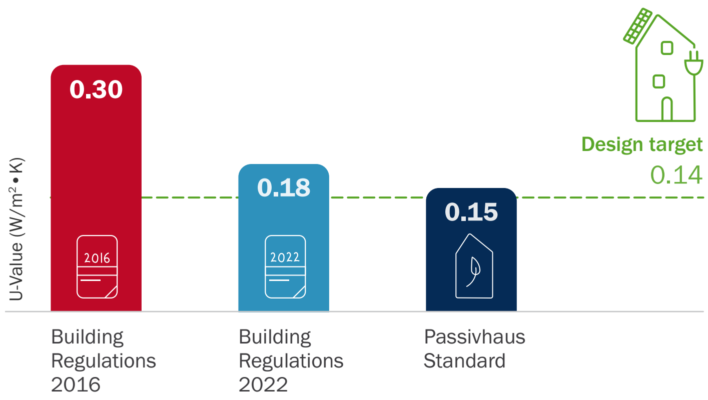


Figure 10: Comparison of External Wall U-values – Building Regulations, Passivhaus and ‘Swansea Standard’

‘Swansea Standard’ services

Ventilation

Improving insulation and draught-proofing reduces heat loss. Homes that are very airtight can allow moisture and pollutants from everyday activities such as cooking and washing to become trapped causing health issues. Ventilation systems can be installed to provide clean, fresh air.

Whole house Mechanical Ventilation Heat Recovery (MVHR) systems remove stale, damp, warmer air from 'wet' rooms like kitchens and bathrooms. This waste air is passed through a heat exchanger where warm air is extracted and passed to incoming fresh air, without mixing the two airflows. The incoming fresh, filtered, warmed air is fed into living spaces such as bedrooms and living rooms. The main components of an MVHR system are shown in Figure 11. Each room has specific airflow needs, according to UK Building Regulations [8], to ensure adequate ventilation. Matching measured airflow to design targets is essential for good indoor air quality, moisture control, thermal comfort and regulatory compliance.

A MVHR system can be set to 'boost mode' for when high levels of moisture are being generated such as when using the shower or hob. A 'bypass mode' should be used when external temperatures are high so that waste heat is not recovered to prevent overheating.

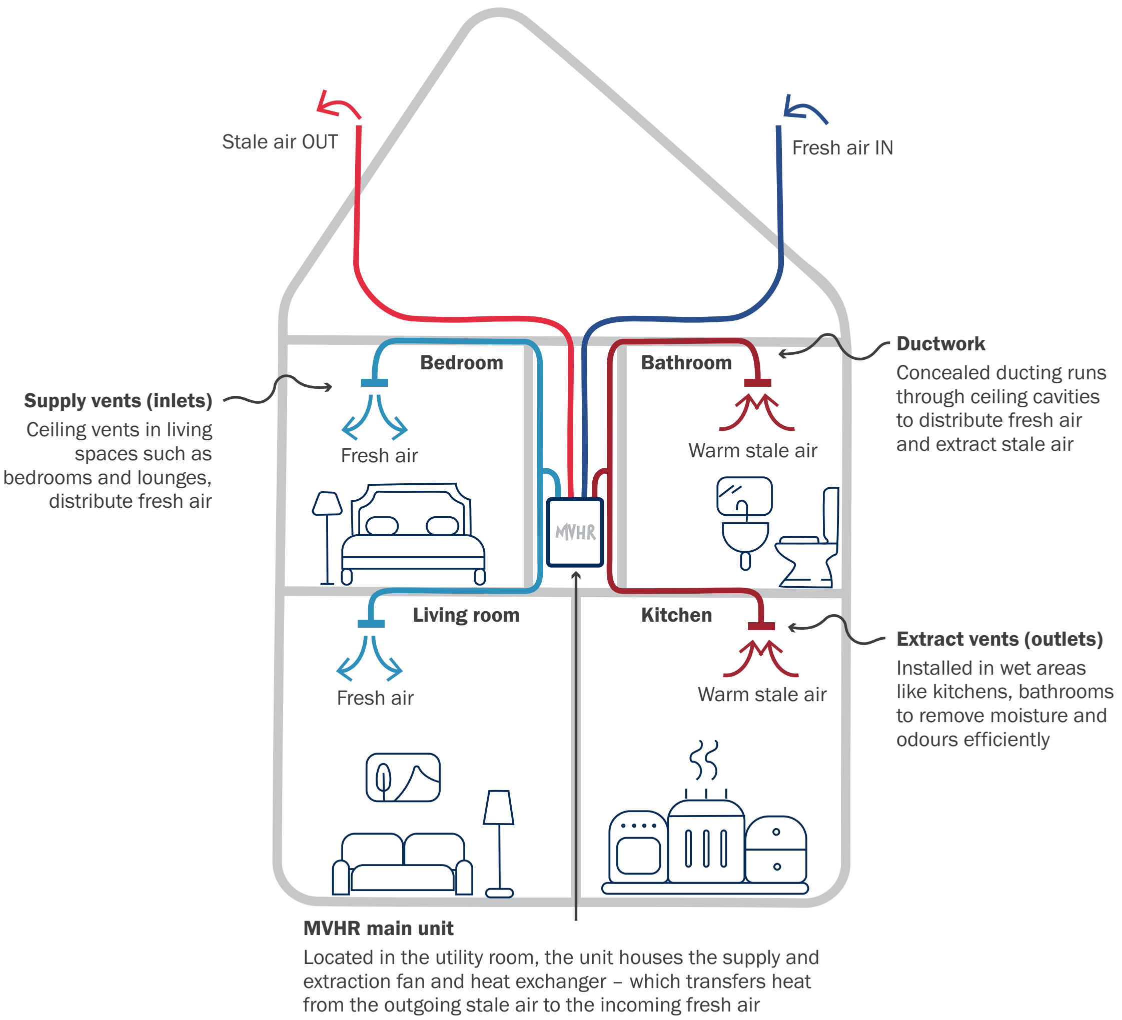


Figure 11: An example of a Mechanical Ventilation Heat Recovery (MVHR) system

Heating and hot water

Space heating and domestic hot water (DHW) are provided by a Ground Source Heat Pump (GSHP) powered by electricity. Closed loop pipework has been installed vertically into the ground in each garden. A heat pump unit is located in each kitchen with radiators providing heat in each room as illustrated in Figure 12.

Heat is supplied at a lower temperature than a typical gas heating system, so radiators are slightly larger. The DHW system includes a cylinder with a 3 kW electric immersion heater to provide hot water on demand. The heat pump typically heats water to around 50°C. A weekly 60°C anti-legionella cycle is included as good practice.

A screen located in the living room allows residents to control whether heat is fed to the radiators or the DHW cylinder. Temperature can be set to meet comfort needs and hot water can be timed. Energy use per month is displayed to allow residents to make comparisons in use. Each radiator has a Thermostatic Radiator Valve (TRV) allowing residents to control individual room temperatures.

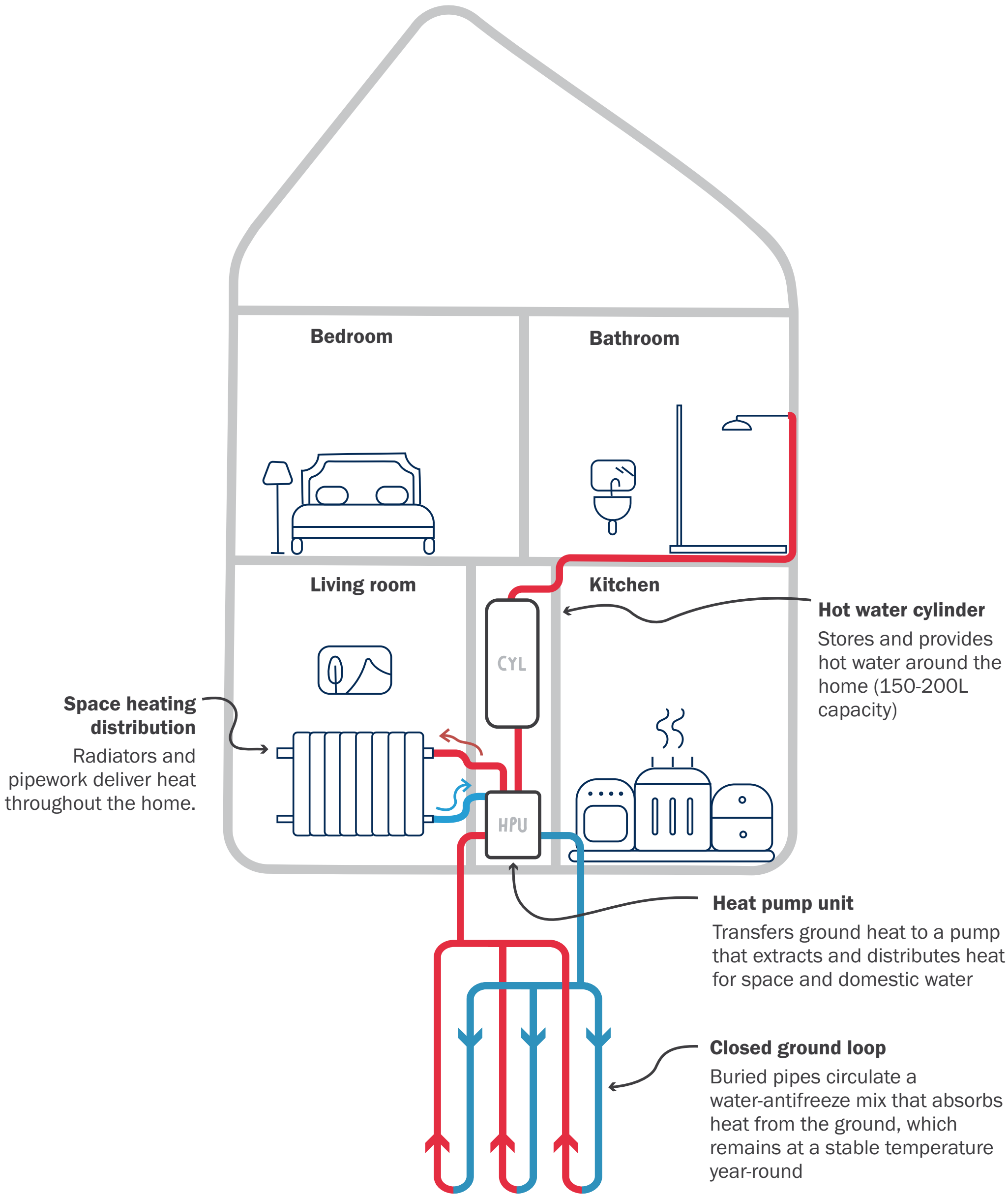


Figure 12: A Ground Source Heat Pump heating and hot water system

Renewable energy and storage

Building Integrated Photo-voltaic (BIPV) panels are installed together with a single-phase inverter which converts energy from DC (from the BIPV) to AC (to be used in the home). A lithium-ion Tesla Powerwall 2 battery has been installed in all homes with a storage capacity of 13.5 kWh.

Figure 13 illustrates how the BIPV-battery-grid system interacts depending on resident energy use. Electricity generated by the BIPV is used directly by the resident as it is needed. If there is excess electricity that is not being used at the time of generation, this is stored by the battery. Once the battery is full and excess power is still being generated by the BIPV energy flows back to the electricity grid.

At times when renewable energy is not being generated by the BIPV – at night or on very cloudy days – electricity is taken from the battery or if fully discharged, the electricity grid. BIPV capacity across the four sites ranges from 3.78 kWp to 4.57 kWp. This was based on the size of the roof available and the angle of the pitch of the roof.

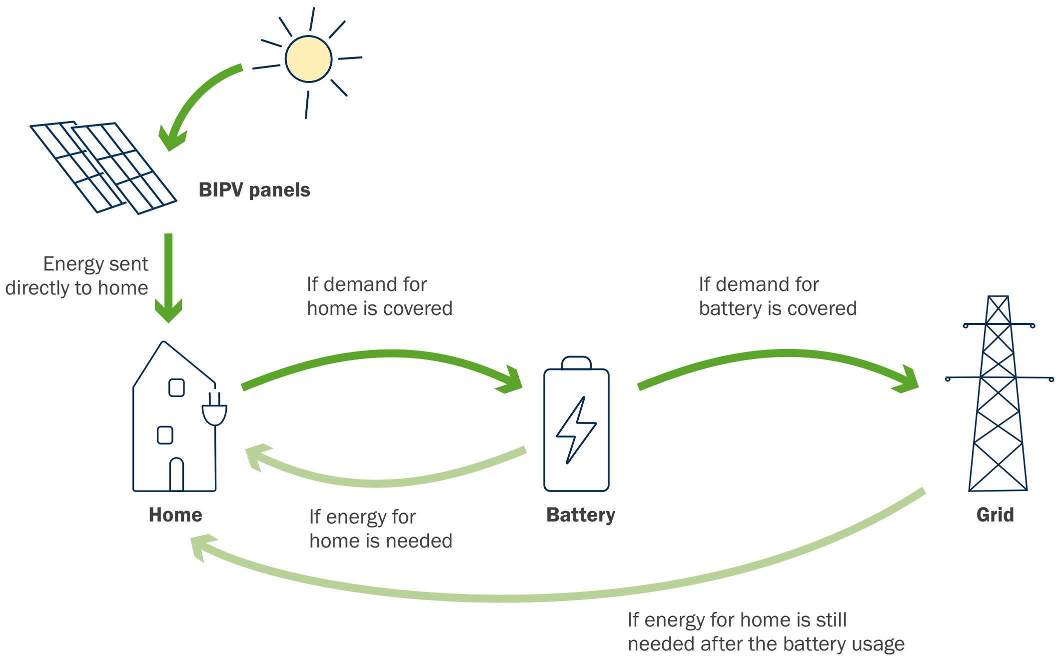


Figure 13: Interaction between the BIPVs, battery and national grid

3 Monitoring and evaluation

3.1 Monitoring approach

Monitoring and evaluation of the built environment to provide reliable and useful evidence is time consuming, expensive and needs to take place over long periods of time. A balance must be found between the level of data that provides useful evidence with limited resources available [15, 18, 19, 20].

A monitoring and evaluation plan was developed for the whole project, for each site and for individual homes. Monitoring was planned around completion of homes across the four sites which were staggered, as well as for measurements to take place at appropriate times throughout the year. For example, thermography and U-value tests need to be taken during colder periods of the year when the temperature difference between inside and outside is greatest.

A two-tiered monitoring approach was taken, illustrated in Figure 14.

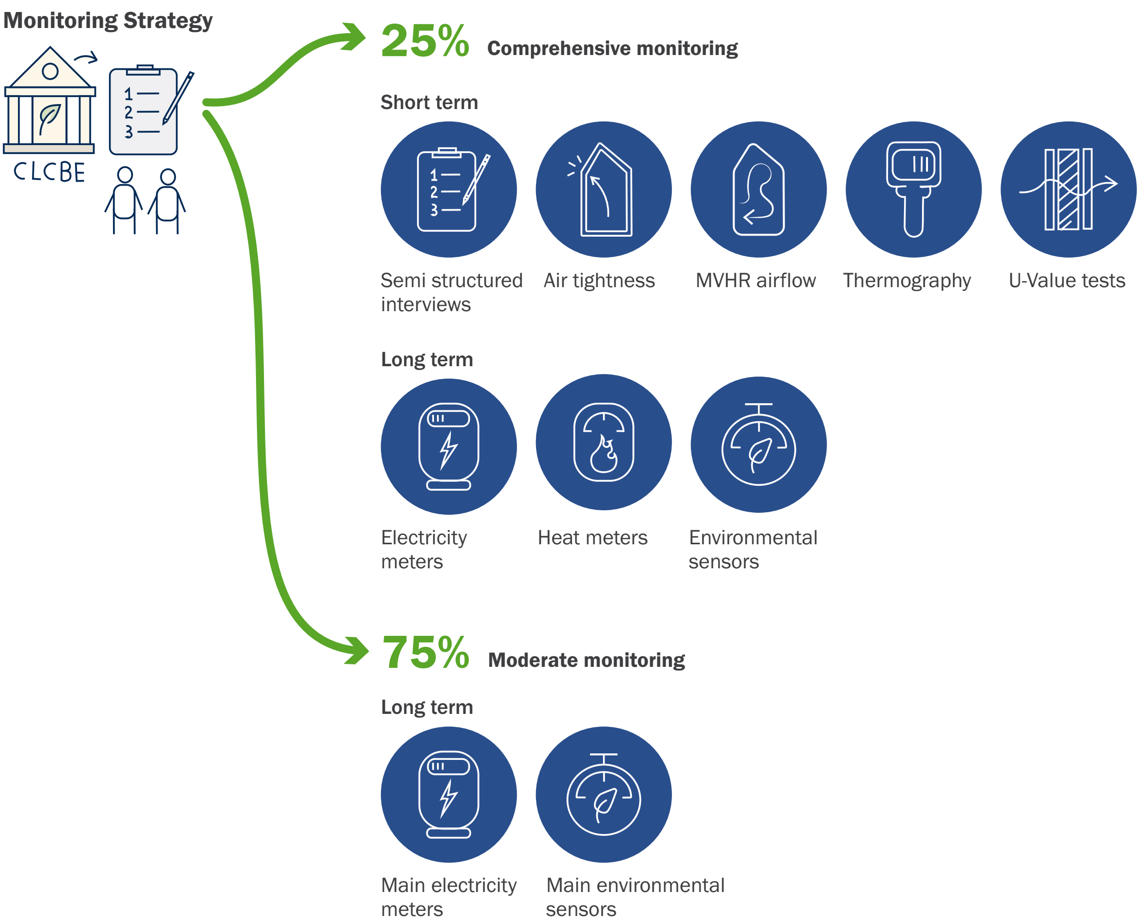


Figure 14: Two-tiered monitoring approach across four sites

Comprehensive Monitoring Approach – 25% of a mix of homes across the four sites that were monitored, to include:

- **Short-term** – in-situ U-value measurements of external walls, airtightness tests of the thermal envelope, MVHR assessment and thermographic inspections to detect heat loss and construction quality issues took place. Semi-structured interviews with residents helped gather information on the solutions, the home and energy use.
- **Long-term** – installation of electricity meters to record electricity imported and exported, electricity consumption by the different components of the system – MVHR, GSHP and immersion heaters, battery (charge/discharge) and electricity generation from renewables. Heat meters were also fitted to measure energy delivery for space heating and DHW.

Temperature and relative humidity sensors were placed in the living room, kitchen and each bedroom. CO_2 sensors were positioned in the most frequently occupied space, usually the living room.

Moderate Monitoring Approach – 75% of homes across the four sites were included:

- **Long term** – installation of electricity meters to record import and consumption.

3.2 Monitoring methods

Data was collected on-site and remotely using a consistent approach across all four sites. Long-term monitoring data was collected remotely which helped to minimise travel costs and carbon emissions. Remote data was transmitted via the internet to a third-party server which was then retrieved and processed ensuring a standard, efficient and scalable process to take place throughout the four years and across all four sites. Each site was monitored for a minimum of two heating seasons enabling data to be compared. The project ran from January 2021 to June 2025.

External wall U-values

A U-value indicates how easily heat passes through elements of a building like a wall, a window or a roof. The lower the U-value the better the thermal performance, helping to keep a home warm in winter and cool in summer.

Measurements were carried out at various points on walls following the BRE 2016 guide [21]. Equipment was installed for 7–14 days at each location and was carried out across the four sites. Figure 15 shows the U-value equipment set up on a north-facing wall away from direct sunlight, windows and corners with measurements taking place at two heights.

Figure 15: U-value measurement test equipment set up and detail of measurement point

Airtightness

Airtightness indicates how much air is leaking through gaps and cracks in walls, windows, doors and the roof of a home. It is recorded as an air permeability rate – the amount of air that passes through the outer surface of a building under a standard pressure (50 Pa). A high level of airtightness helps to maintain moisture levels and controlling air quality achieving building regulations[21].

A blower door test was used following the relevant ISO standard. A fan is positioned in an external door, as illustrated in Figure 16 which creates a pressure difference between the inside and outside of the home, with pressure typically 50–75 Pa. As the fan pulls air out of the home, sensors measure how much air leaks in through gaps and cracks.

Figure 16: Blower door equipment set-up to carry out an airtightness test

Points of heat loss and moisture

Thermographic images can be used to detect thermal issues like air leaks or thermal bridges, areas of poor insulation and moisture issues that could impact building integrity or indoor air quality. Images were taken in autumn/winter when the temperature difference between inside and outside was greatest. Photos were captured from both inside and outside of the building while the blower door was operating to emphasise points of air leakage.

Energy use

Understanding the amount of energy used by residents and generated and stored by technologies shows how well a system performs. Energy meters were installed within the homes to collect the following data:

- Import: Electricity used from the grid and paid for by the residents.
- PV generation: Total electricity generated by PV panels.
- Electricity from PV directly: Electricity from the PV panels used immediately in the home.
- Battery charge: Electricity from the PV panels used to charge the battery.
- Battery discharge: Electricity from the battery used in the home.
- Export to grid: Surplus electricity from the PV panels sent back to the grid.

As an example, a more efficient heating and DHW system will use less electricity to provide the same amount of heat. Understanding how a GSHP performs in real-world conditions will encourage further installations if performance meets or exceeds as designed expectations. The amount of heat delivered by the GSHP was monitored using heat meters with heat used for space heating and domestic hot water separated.

The performance of the heating system was calculated using Seasonal Coefficient of Performance (SCoP) which indicates how much heat is delivered for each unit of electricity used over a whole heating season. A higher SCoP indicates more heat delivered using less electricity, therefore helping to save money on energy bills and lowering CO_2 emissions.

Thermal comfort

Thermal comfort is the feeling of satisfaction with the environment they are in. This can relate to temperature and level of moisture in the air (humidity). Maintaining a temperature and level of humidity is essential to ensuring a comfortable and healthy living environment for residents.

Electronic sensors that monitor temperature and humidity are placed in the living room, bedroom(s), kitchen and bathroom avoiding direct sunlight or heat sources, as illustrated in Figure 17.

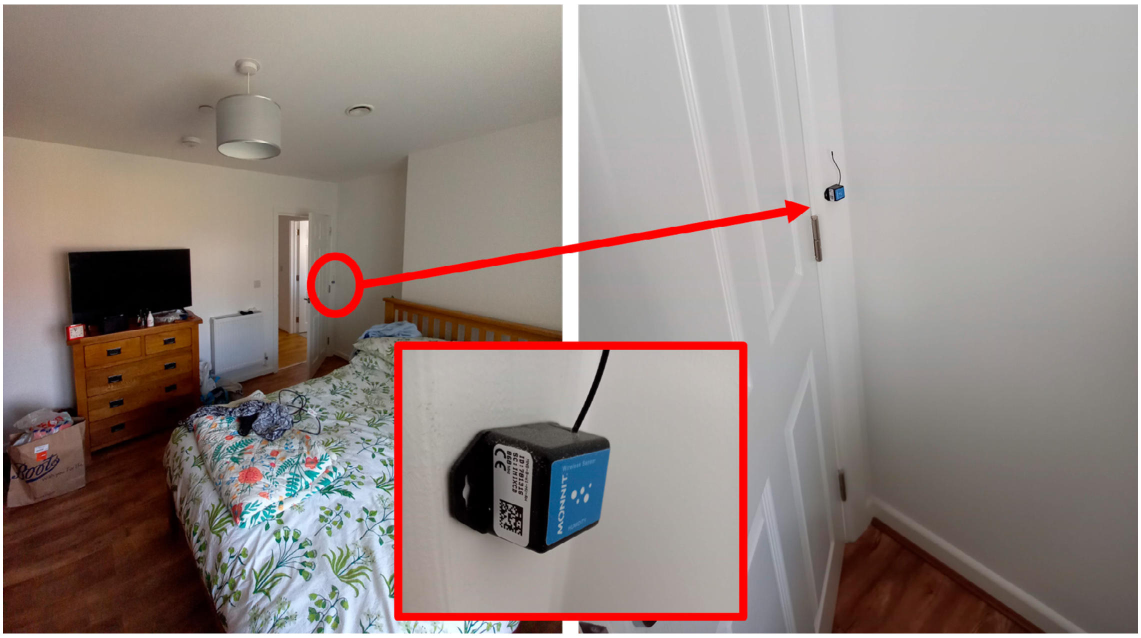


Figure 17: Temperature and Relative Humidity sensor

Indoor air quality

CO_2 concentrations were measured using sensors installed in living rooms, typically the most frequently occupied spaces. An example of a sensor installation is shown in Figure 18. Measurements are taken as 'parts per million' (ppm).

Figure 18: Carbon dioxide (CO_2) concentration sensor

MVHR performance

The performance of an MVHR system relies on correct installation and commissioning. For an MVHR system to work as designed, it needs to be balanced correctly so that the air flow supplied to the home should equal to the air extracted. Air flow rates at each supply and extract terminal were monitored following guidance from UK Building Regulations [22]. A balometer was used that fits securely over an air grill that measures the rate of airflow accurately as seen in Figure 19.

Figure 19: Air flow test

Weather conditions

The weather impacts on the amount of energy used within a home, comfort and overall performance of the systems. Monitoring weather conditions helps understand variability throughout a year and between years. This can be important if weather extremes are experienced. A weather station was installed in a garden of one of the homes that was being monitored. A sensor was installed at each of the four sites to monitor air temperature and relative humidity to compare with weather station data.

Resident engagement and feedback

Resident feedback is essential for understanding how well a home performs. Semi-structured interviews were carried out with one resident from each of the comprehensively monitored homes and collected information about occupancy and general household, comfort and health, facilities and control and energy and cost. Sixty five interviews were carried out across three years – 21 in 2023, 20 in 2024, and 24 in 2025.

4 Results

21 homes were monitored comprehensively, with 44 homes monitored moderately. The monitoring and evaluation results for all four sites are described below.

4.1 Energy use intensity

Energy Use Intensity (EUI) describes how much energy a home uses related to its size, expressed as kilowatt-hours per square meter for a full year (kWh/m² year) allowing homes of different sizes to be compared. Monitoring data from energy meters is used to calculate the EUI as illustrated in Figure 20.

Figure 20: Energy Use Intensity calculation

Figure 21 illustrates the EUI for flats, houses, and bungalows comprehensively monitored across the four sites, how they perform against similar homes built in the same era and against key Standards and targets. The source of energy is also shown, either from on-site renewables or the national grid.

A typical home built in 2017 uses between 120 to 143 kWh/m² year. The 'Swansea Standard' homes use half of this amount with half of the energy used coming from on-site renewables. The amount of energy home type indicating that residents have a major impact on how energy is used within similar homes. This is more evident within the flats and houses that the sample is greater to the bungalows.

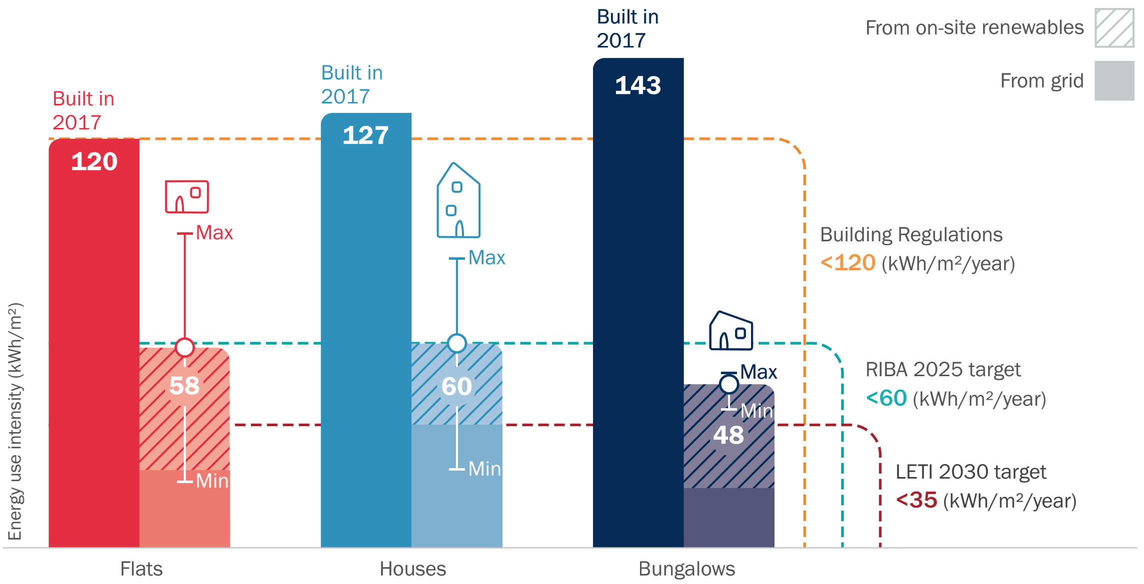


Figure 21: Annual EUI per SC property types compared to typical homes built in 2017

4.2 Energy cost to the resident

Annual energy cost is the amount of money a household pays for energy it uses from the grid over a yearly period. Energy generated by the BIPV used directly or stored by the battery and used later does not cost the resident. Annual energy cost is calculated from the monitored electricity imported from the grid as shown in Figure 22.

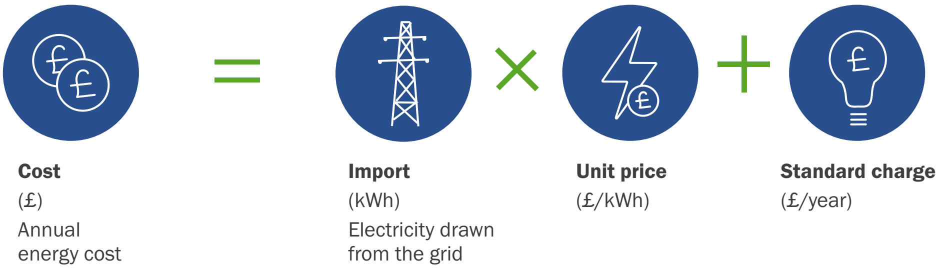


Figure 22: Annual energy cost calculation

UK government published values were used as standard electricity prices and standing charges [23]. Figures in this report are based on December 2024 energy market values.

Figure 23 illustrates average annual energy cost for different types of homes in Wales (built between 2019 and 2021 from the National Energy Efficiency Data Framework (NEED) [11] as well as the annual energy cost for the new Swansea Standard homes from monitored data.

Homes across all sites illustrate lower annual energy cost compared with the Welsh average for similar properties. Average energy savings are £554 for flats, £584 for houses and £915 for bungalows. The savings are largely due to fabric performance and on-site BIPV generation and battery storage systems. As renewables systems are of a similar size across all homes, smaller-sized homes with less residents (flats and bungalows) import and pay less energy bills.

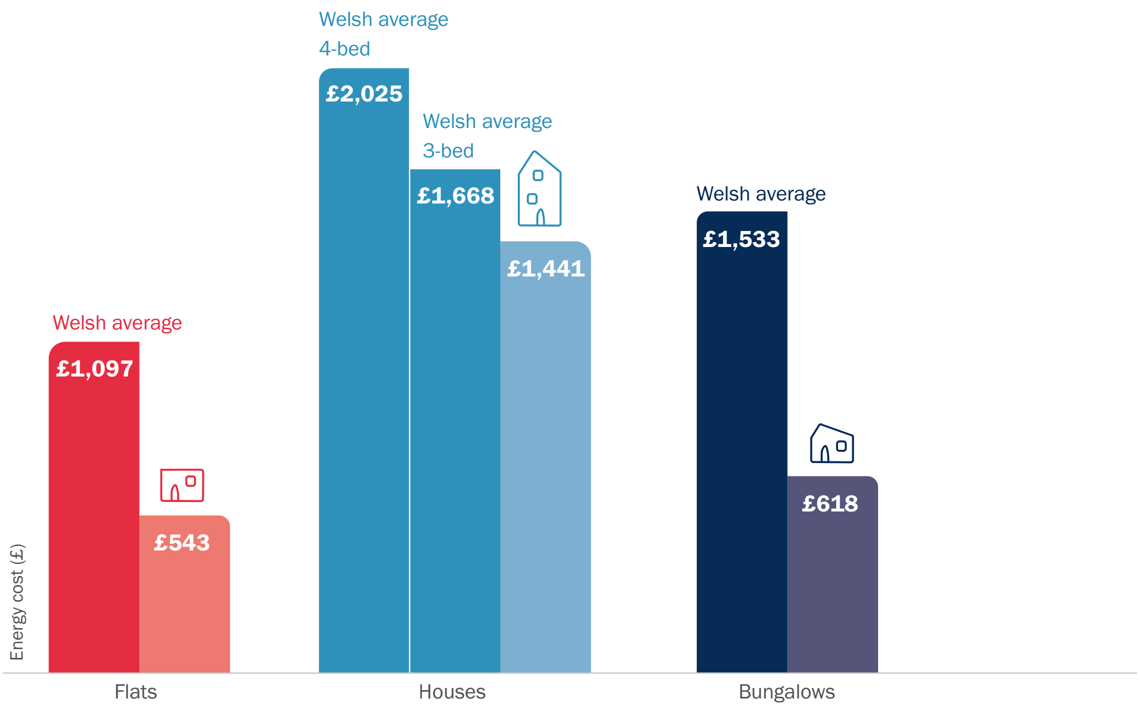


Figure 23: Average annual energy cost per property type

Figure 24 shows the average annual cost savings per property type due to the BIPV and battery. When energy from the BIPV is not used at the time of generation, energy is stored by the battery for use at a later time. If excess energy is not used or stored (when the battery is full) it is exported to the grid.

BIPVs in the flats are slightly smaller (4 kWp) than those in the houses and the bungalows (4.5 kWp). Houses and bungalows can therefore store more energy that can be used when energy is not being generated. Results indicate that residents in houses benefit financially than those living in flats or bungalows as energy use is higher and distributed more evenly throughout the day. More of the electricity generated by BIPV is used directly in the home, reducing export to the grid.

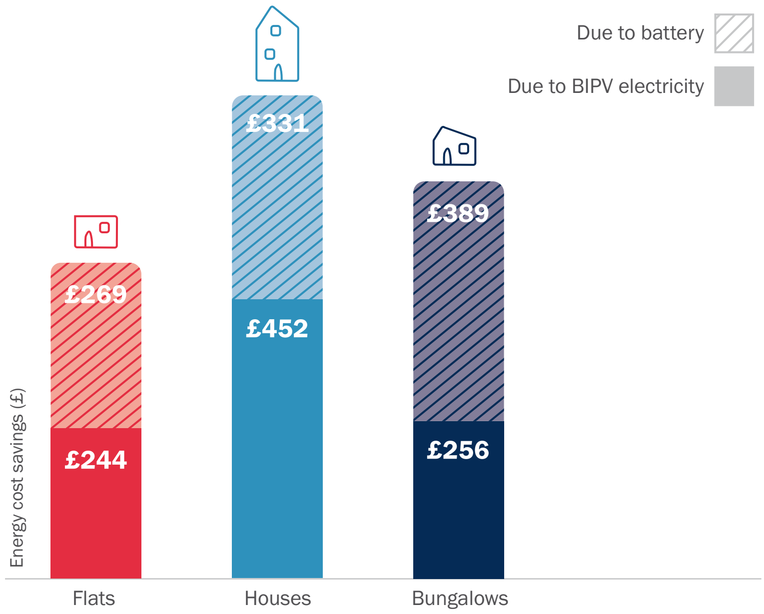


Figure 24: Annual average cost savings provided by BIPV and battery excluding potential export savings

4.3 Carbon dioxide equivalent emissions

Emissions of different gases are released when fossil fuels like coal, oil and gas are burned to produce energy for heating, hot water, lighting and appliances. Reducing these greenhouse gas emissions, such as methane, nitrous oxide, carbon dioxide and others helps limit climate change. A term commonly used to bring all different greenhouse gases together is 'carbon dioxide equivalent emissions' (CO_2e).

CO_2e is calculated by using energy imported from the grid multiplied by a conversion factor [24] which indicates how green the grid is, as shown in Figure 25.

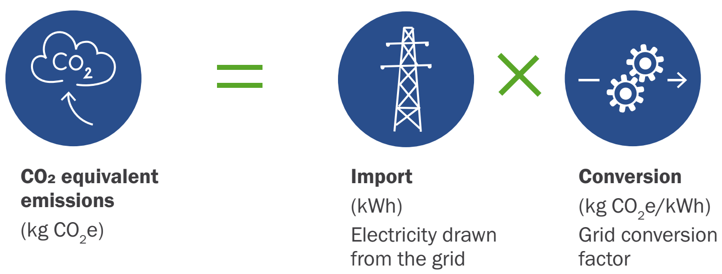


Figure 25: Calculation of CO_2e

When more energy is generated by BIPV or when the residents are not at home, energy is fed back to the grid which helps to reduce the amount of fossil fuels burnt to generate energy, lowering overall CO_2e.

The amount of CO_2e 'avoided' due to excess energy being exported back to the grid is calculated using the formula in Figure 26.

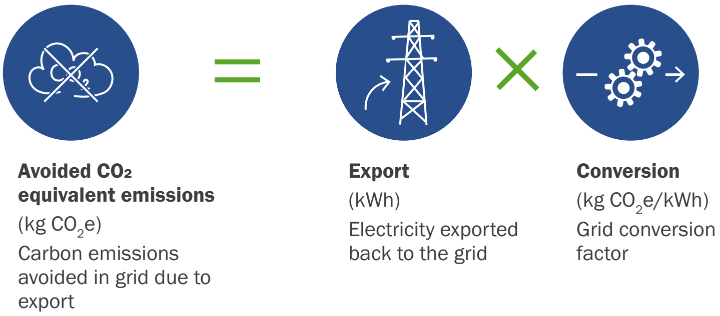


Figure 26: Calculation of CO_2e saved due to grid export

Figure 27 shows the average annual CO_2e per property type as well as CO_2e saved when electricity was exported to the grid and did not have to be generated at a grid level. The graph illustrates that CO_2e are lower than the Welsh average for the same property type. For flats and bungalows, emissions are almost equal to emissions saved and a fifth to the Welsh average. CO_2e are higher for houses as the ability to generate energy per floor area is less and occupancy is higher requiring more energy import from the grid. However, levels are still half the level of an average Welsh home.

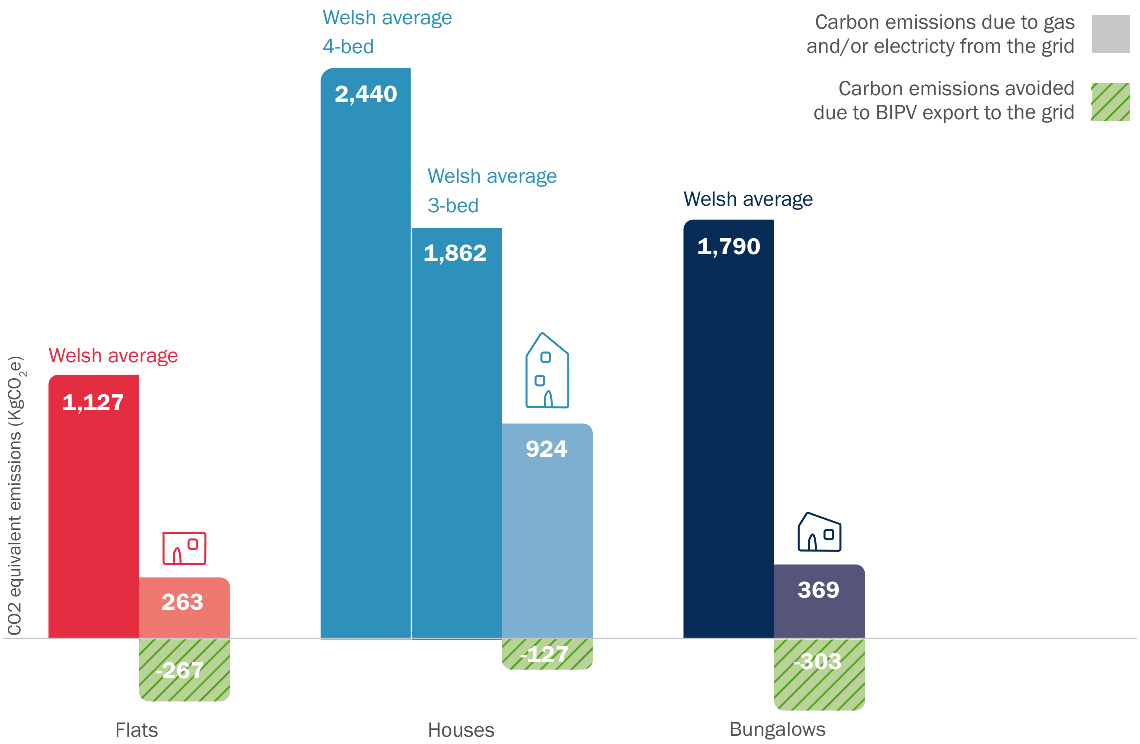


Figure 27: Average annual CO_2 equivalent emissions per property type and CO_2 equivalent emissions saved due to energy export

4.4 Fabric

External wall U-value

Figure 28 illustrates the U-values of the external walls across all four sites. The Swansea Standard design target was set at 0.14 W/m²/K. Building Regulations target at the time of design and construction was 0.30 W/m²/K. Building Regulations target is achieved across all sites, Swansea Standard was achieved on sites 1 and 4 but was exceeded at sites 2 and 3. Setting up equipment in occupied homes is a challenge, with belongings and furniture creating obstructions in favourable testing locations. The results obtained are considered acceptable.

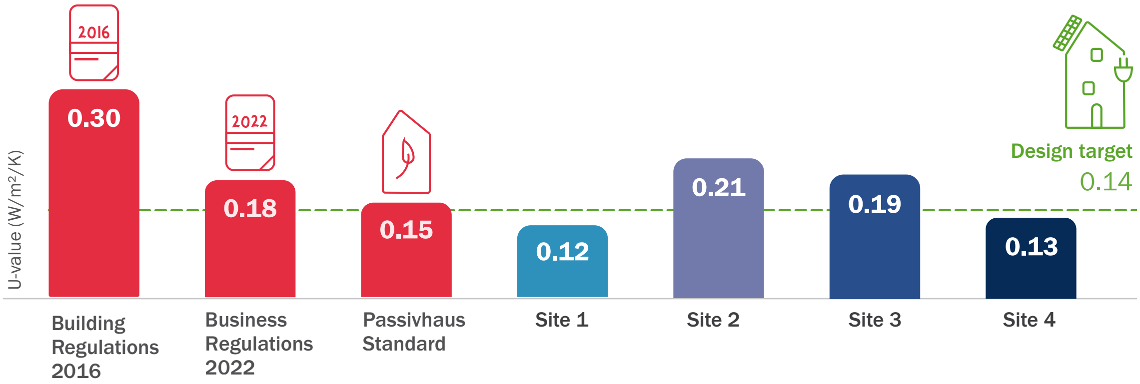


Figure 28: Average external wall U-value across the 4 sites

Air tightness

Figure 29 presents air tightness targets and results. This includes the pre-2022 targets for Building Regulations (<10 m³/h·m² @50Pa) which is when the homes were designed. Post-2022 Building Regulation targets is set at 8 m³/h·m² @50Pa. Figure 29 also includes the monitored UK Government Standard Assessment Procedure (SAP) values for the different property types as well as the Swansea Standard design target of <5 m³/h·m² @50Pa.

The Swansea Standard design target for airtightness is achieved for all property types and are close to SAP targets. The LETI Design Guide targets are illustrated in the graph but would require significant financial investment to achieve <1 m³/h·m² @50Pa

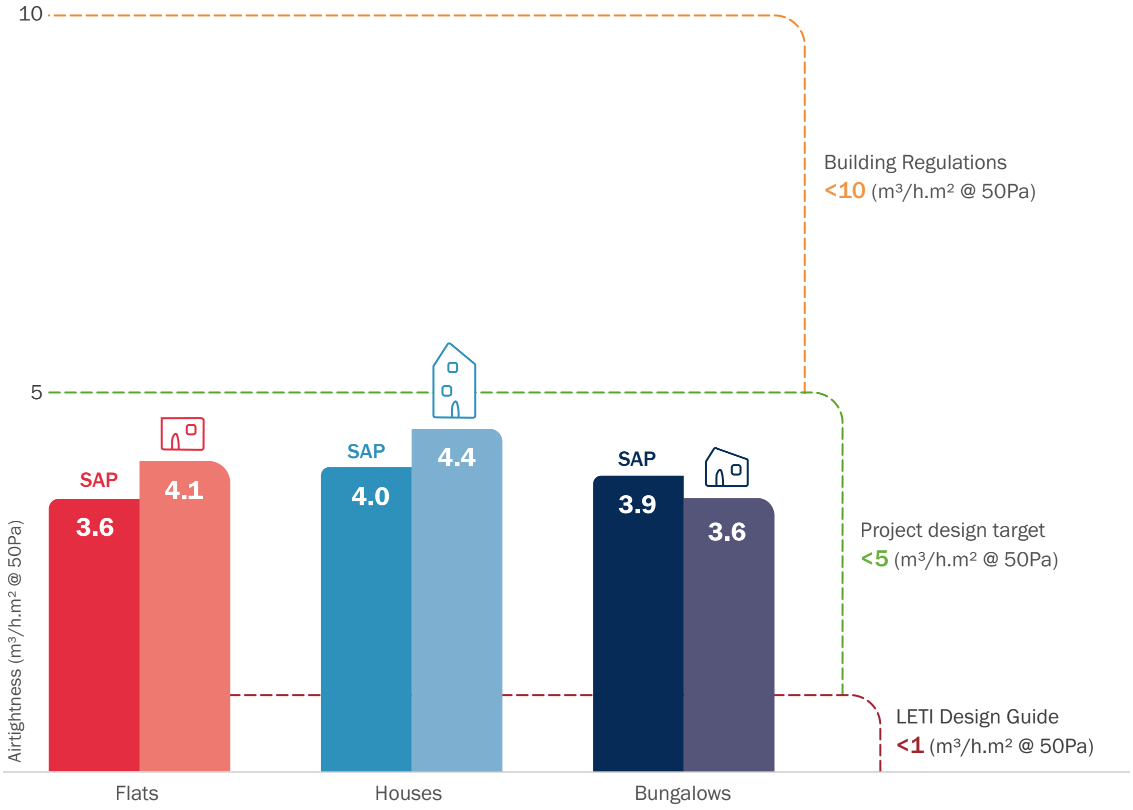


Figure 29: Airtightness results compared to Swansea Standard design targets, 'as built' SAP values, Building Regulations and the LETI Design Guide

Thermal imagery

Thermographic images [25] of the walls, as illustrated in Figure 30 demonstrate an evenly distributed temperature indicating evenly installed insulation.

Figure 30: Photo and thermal image taken whilst home was over-pressurised

On reviewing details of images, improvements across all four sites could be made to reduce heat loss at:

- seals around window and door frames (Figure 31).
- junctions between external walls and ceiling or floor (Figure 32).
- insulation at the edge of the loft hatch (Figure 33).

Figure 31: Thermal image of heat loss around door frame

Figure 32: Thermal image of heat loss at junction between floor and external wall

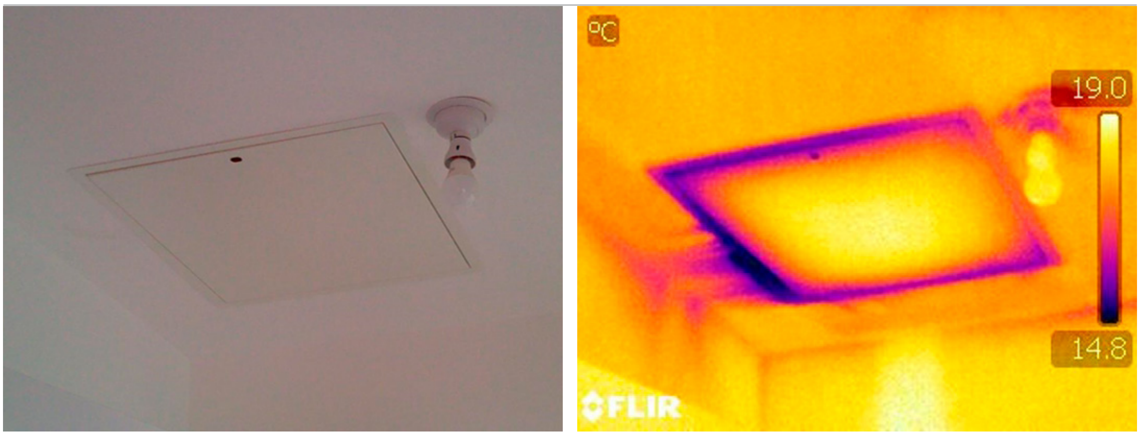


Figure 33: Thermal image of heat loss at edge of loft hatch

4.5 Renewable energy supply and storage

The more renewable energy that is generated and consumed on-site, the less energy needs to be imported from the grid resulting in lower energy costs and reduced CO_2 equivalent emissions.

Figure 34 indicates the average annual amount of energy that each property type uses and where that energy comes from. The results are compared to the Wales average for the same property types where both gas and electricity are used. Electricity imported from the grid is what residents pay for.

Flats and bungalows are considered 'net-zero' as they export as much energy as they import. The contribution from BIPV is similar for houses and bungalows and smaller for the flats due to the slightly smaller BIPV capacity.

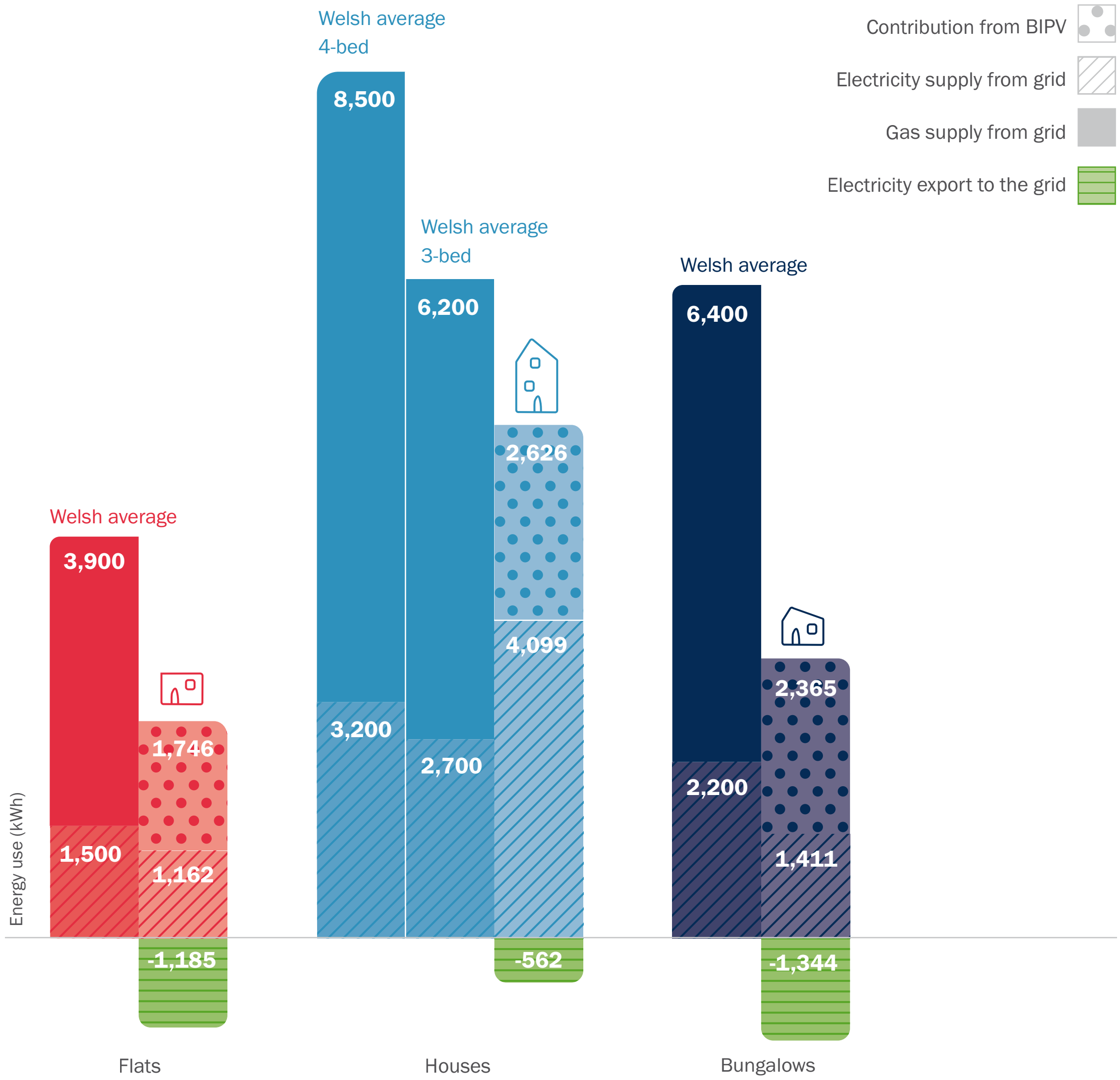


Figure 34: Average annual amount of energy that each property type uses compared to the Wales average including source of energy

Figure 35 illustrates the energy source for each of the property type – directly from the BIPV, stored and released by the battery or from the electricity grid. 47% of energy comes from on-site renewables.

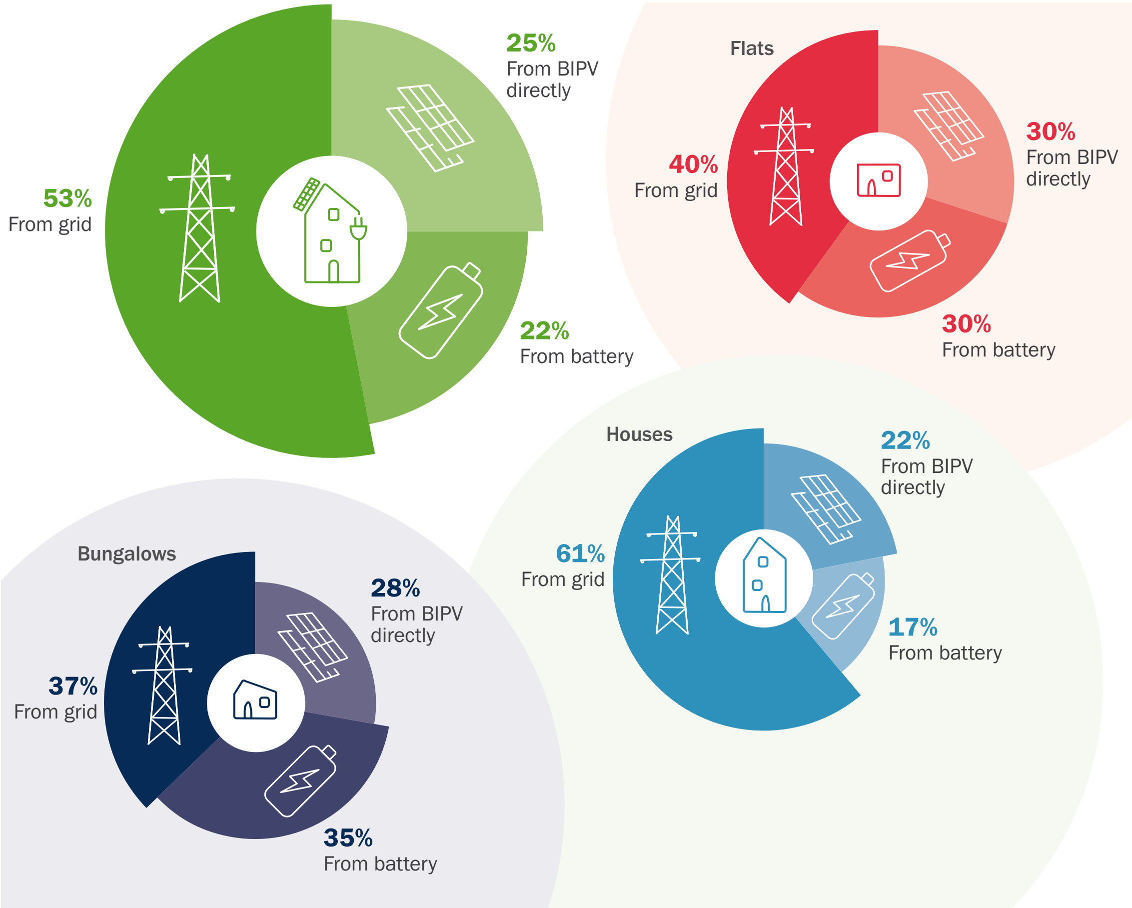


Figure 35: Average annual contribution from BIPV, battery and from the electricity grid for all homes and for the three property types

GSHP energy use and efficiency

Measuring energy use and efficiency helps to show how well a GSHP performs in real-world conditions. A more efficient system uses less electricity to provide the same amount of heat and hot water. Performance calculations are often based on laboratory tests.

Figure 36 shows a comparison of the monitored results of the GSHP energy use and efficiency compared to the energy use for space heating and hot water for an average Welsh house. Energy use is one-third of that of a similar house type with a gas heating system, illustrating the efficiency of a GSHP compared to a gas heating system.

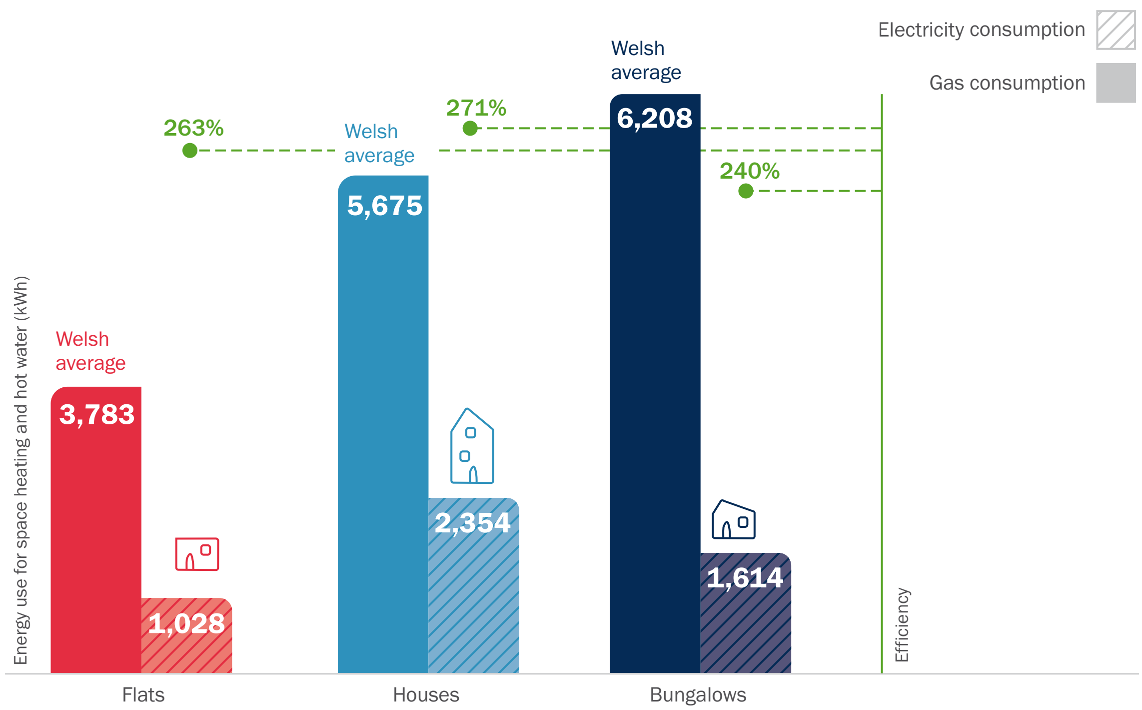


Figure 36: Average annual energy use for heating and hot water and efficiency for GSHP across 3 house types compared to Welsh average with efficiencies indicated in green

4.6 Comfort

Temperature and humidity results were recorded and compared against the range of thermal comfort depending on the season and the use of living space as presented in CIBSE Guide A [6].

Hourly thermal comfort for all homes is presented in Figure 37, which were mainly within the acceptable ranges suggested by CIBSE. During winter, minimum temperature is considered 21°C by CIBSE, which in some cases was above the desired temperature set by the residents indicating a lower-than-expected comfort level at 27%. Subjective comfort levels were reached during winter as demonstrated by the survey results.

The maximum comfort temperature limit for summer according to CIBSE is 25°C, which therefore indicates overheating at 16% of the time. Indoor temperature and relative humidity levels are shown in Figure 38 and Figure 39 illustrating temperature variation in a flat where overheating was experienced during summer. The MVHR helps to keep relative humidity within acceptable ranges preventing damp and moisture issues.

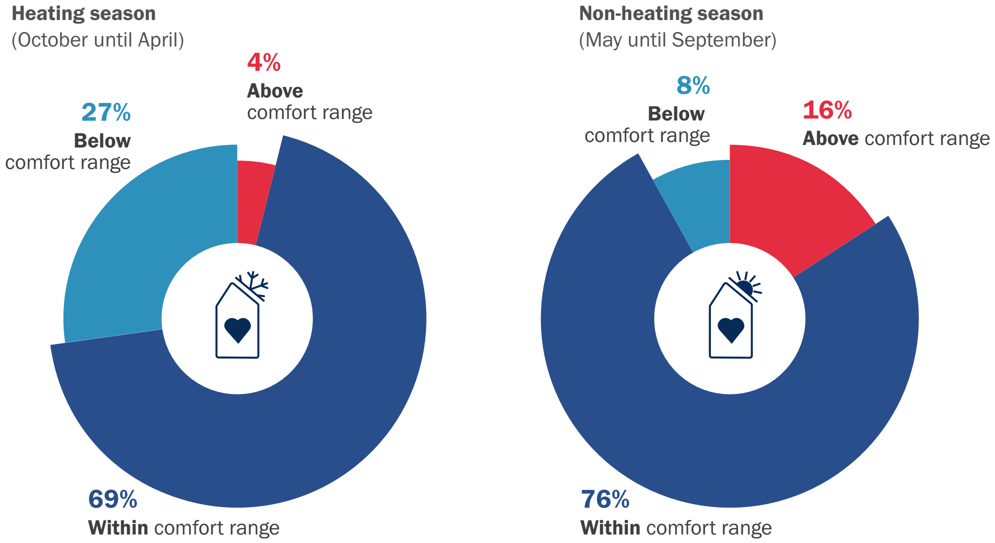


Figure 37: Hourly thermal comfort ranges across all homes during winter and summer

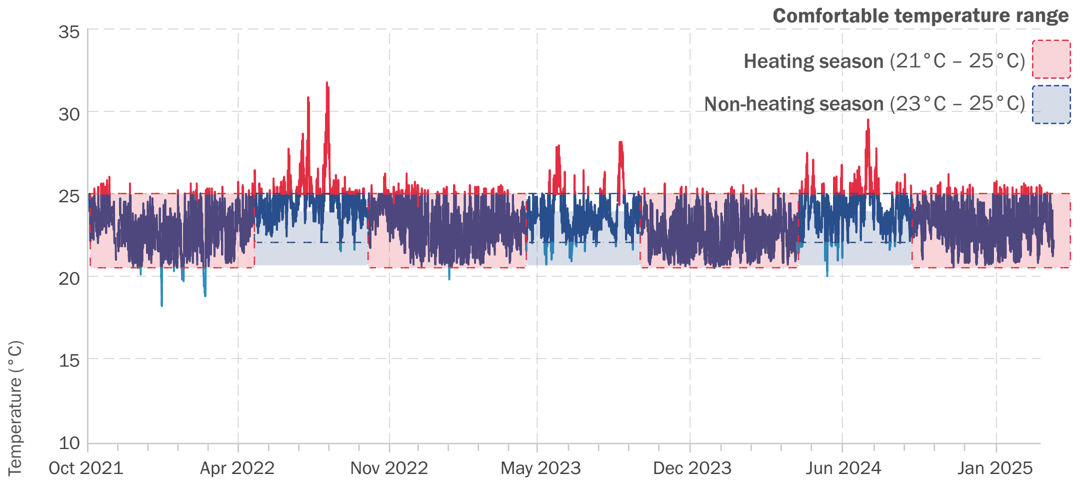


Figure 38: Range of indoor temperature – example flat at Site 1

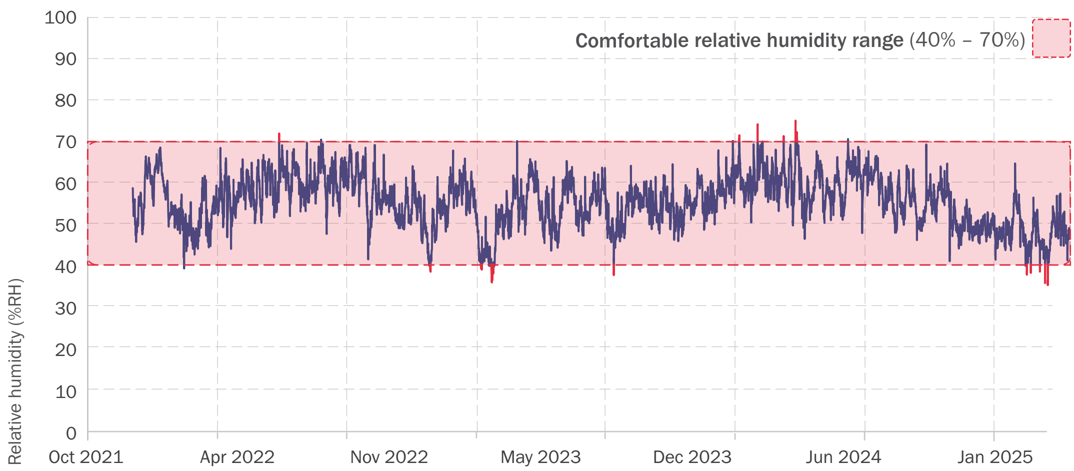


Figure 39: Range of relative humidity levels – example house at Site 4

4.7 MVHR supply and extract air flow

Figure 40 illustrates the results of MVHR tests. Results taken immediately after construction indicated that the air flow rate was beyond the acceptable range (illustrated by the red circles). Re-commissioning was requested due to poor performance. Following the recommissioning, air flow rates in all homes were found to be compliant. The value of monitoring is illustrated where issues could be identified and solved prior to residents moving in. The need for high-quality commissioning is also demonstrated to ensure optimal MVHR system performance.

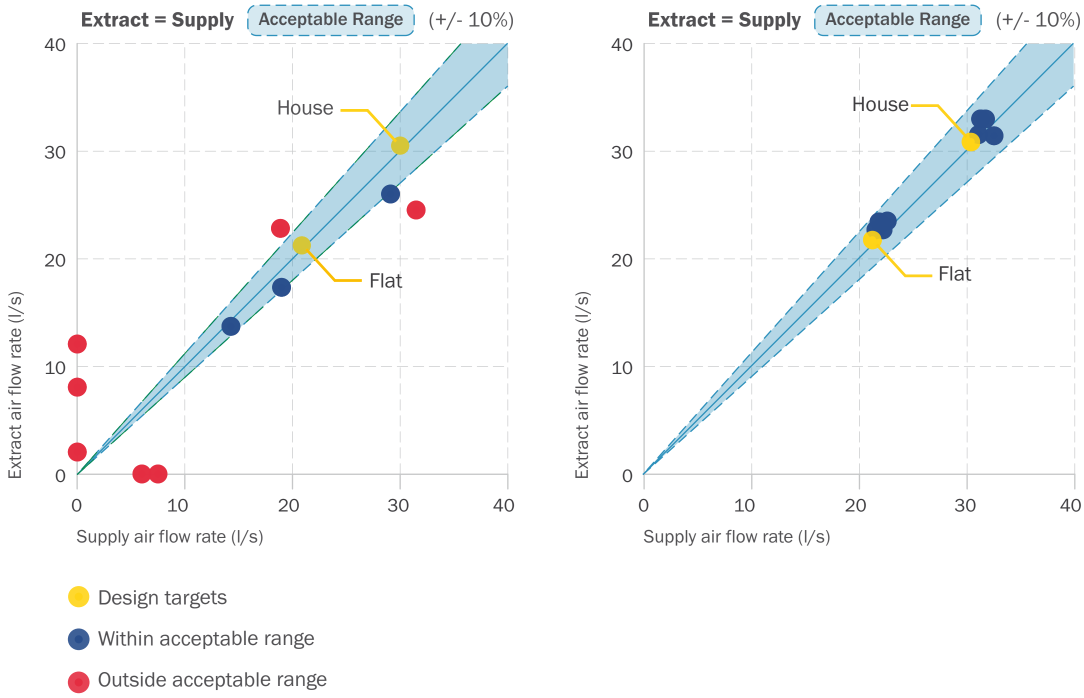


Figure 40: Post-construction air flow measurements taken immediately (left) and after re-commissioning (right) of MVHR systems

4.8 Indoor air quality

CO_2 concentrations can be affected by the number of residents, activity levels, ventilation rates and building airtightness. CO_2 was measured using sensors installed in living rooms, as they are typically the most frequently occupied spaces.

Monitored CO_2 levels taken over 3 years, were compared to CO_2 concentration guidelines [7, 26, 27, 28, 29]:

- 400 ppm – Outdoor baseline
- < 1,000 ppm – well-ventilated space
- 1,000 – 1,500 ppm – inadequate ventilation.
- > 1,500 ppm – poor ventilation; action needed.

For 96.8% of the time, the CO_2 concentrations were below 1000 ppm across all homes. For 3% of the time it was between 1000 and 1500 ppm and for just 0.2% of the time it was above 1500 ppm.

To enhance clarity, the properties were grouped according to the observed CO_2 concentration patterns. The following three patterns were identified based on how consistently they meet ventilation adequacy thresholds:

- 35% of the homes: consistently met the ventilation threshold with negligible inadequate or poor ventilation.
  - At least 99% of the time CO_2 concentrations were well ventilated.
  - Less than 1% of the time CO_2 concentrations indicated inadequate ventilation.
- 35% of the homes: met the ventilation threshold with minimal indication of inadequate or poor ventilation.
  - At least 95% of the time CO_2 concentrations were well ventilated.
  - Less than 5% of the time CO_2 concentrations indicated inadequate ventilation.
  - Less than 1% of the time CO_2 concentrations indicated poor ventilation.
- 15% of the homes: mostly met the ventilation threshold with occasional inadequate or poor ventilation.
  - At least 90% of the time CO_2 concentrations were well ventilated.
  - Just less than 10% of the time CO_2 concentrations indicated inadequate ventilation.
  - 1%–2% of the hours the CO_2 concentrations indicated poor ventilation.

Brief spikes in CO_2 levels are typically caused during periods of cooking or when a larger number of people are together in one room. Action is needed when CO_2 levels remain above 1,000ppm for longer periods. Results from a home in the lower 15%, as shown in Figure 41, illustrates how CO_2 levels can fluctuate over time. It can clearly be seen that most of the time CO_2 levels indicate a well-ventilated space.

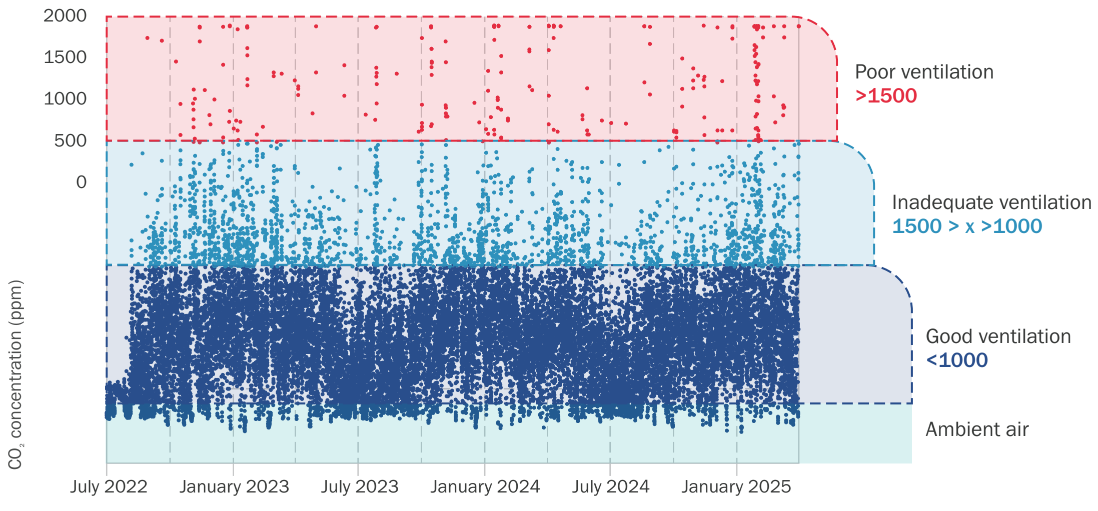


Figure 41: Fluctuating CO_2 concentrations (ppm) in a Swansea Standard home with the majority of measurements at good ventilation levels

4.9 Resident feedback

Semi-structured interviews were carried out with residents to investigate how well homes performed. Responses were analysed to provide insights into how the residents feel about their homes and the systems within them.

Overall resident satisfaction was at 100%, with 59% being very satisfied and 41% satisfied as indicated in Figure 42. Some areas for improvement were identified during interviews, but these were isolated items.

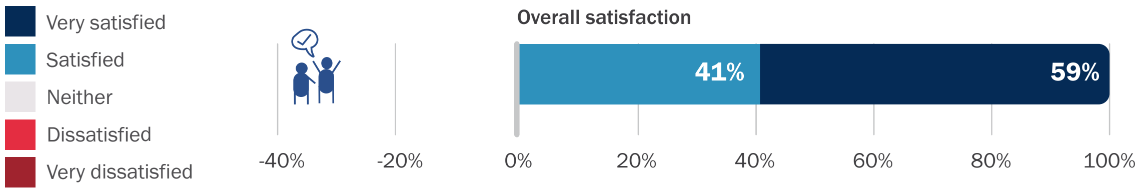


Figure 42: Overall resident satisfaction of homes reported by residents

Perceived comfort

During the winter months 90% of residents reported feeling comfortable or very comfortable in their homes, with only 5% reporting discomfort as illustrated in Figure 43. In summer 57% of residents were satisfied with the indoor temperatures, 14% were neither comfortable or uncomfortable, with 29% experiencing some level of discomfort. Negative feedback was mainly related to overheating and dryness.

Regarding the levels of noise 90% of residents expressed satisfaction. Residents at one of the sites reported noise from the energy storage system. Most residents were pleased with both artificial and natural lighting with only 5% requiring brighter artificial lighting.

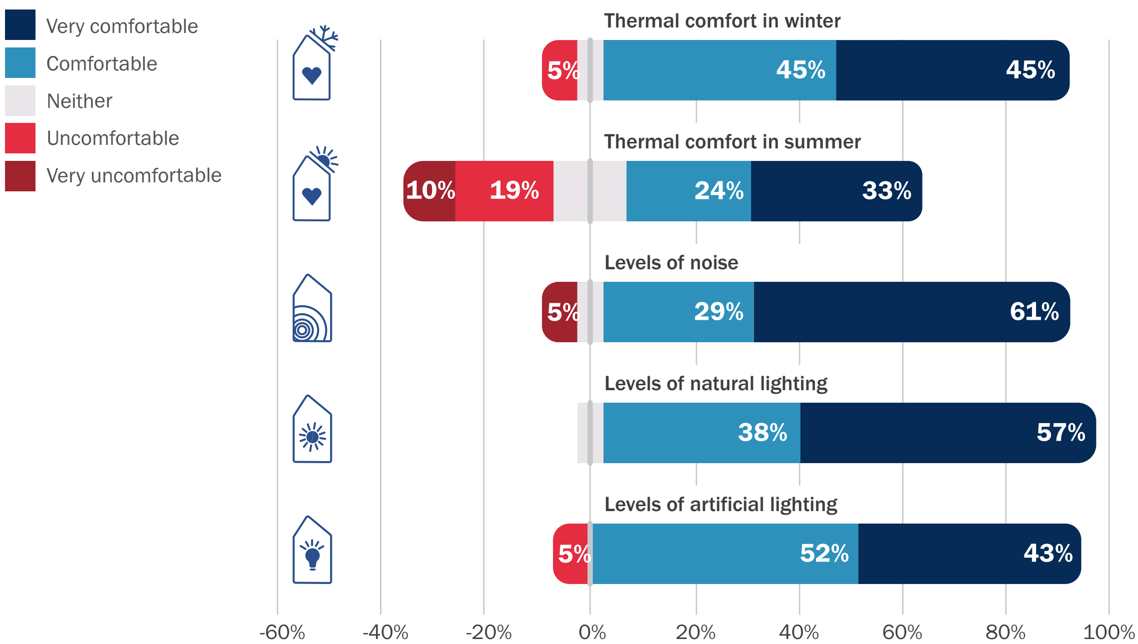


Figure 43: Perceived comfort levels reported by residents

Perceived impact of home on health

When asked about the impact of their home on their health, 60% of participants reported a positive effect, while 30% felt neither a positive or negative impact. 10% reported a negative or very negative impact as illustrated in Figure 44 which was related to specific technical issues that caused stress rather than related to indoor environmental quality.

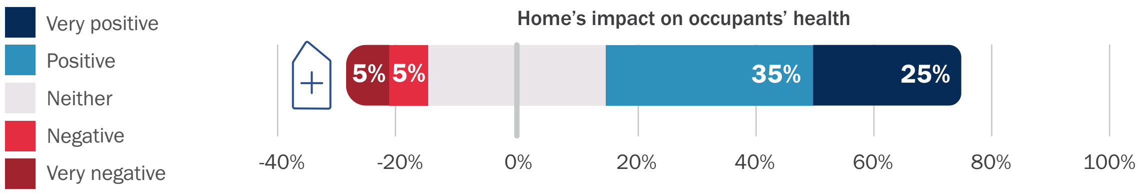


Figure 44: Perceived impact of home on resident health

Perceived indoor air quality

Residents provided feedback on their experience of air movement, air quality and humidity. Nearly two-thirds (64%) of residents were satisfied with the level of air movement in their home, while 31% felt neutral, and 5% were dissatisfied (Figure 45).

Ninety one percent of residents provided positive feedback about the air quality in their homes. 84% of residents reported satisfaction with humidity levels with 14% expressing dissatisfaction. The negative feedback related to dryness of air experienced throughout the year.

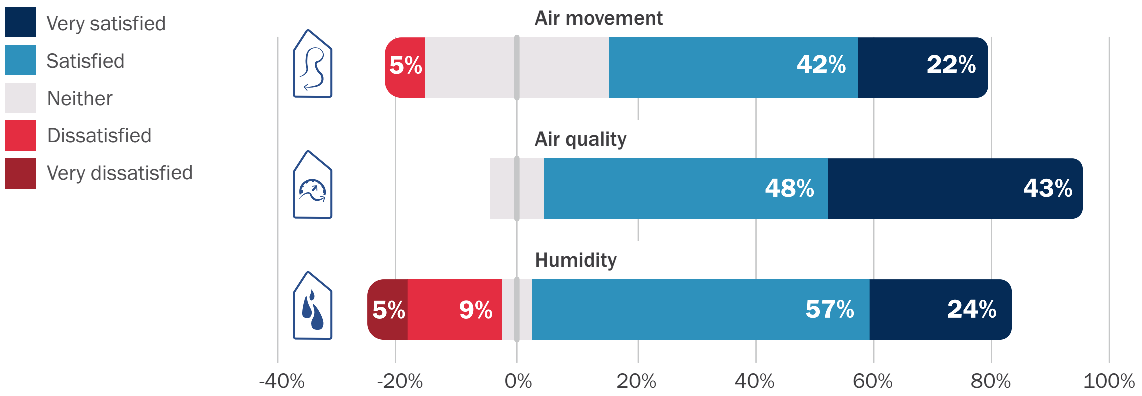


Figure 45: Perceived air quality within indoor environment

The majority of residents reported no problems with damp and mould, while 11% mentioned having experienced some issues (Figure 46). Two common issues were reported during the interviews:

- water leaks were experienced at adjacent properties which caused short term water infiltration issues that have been resolved.
- condensation on windows and issues with window seals were reported. Some had been rectified at the time of the interview, others had not.

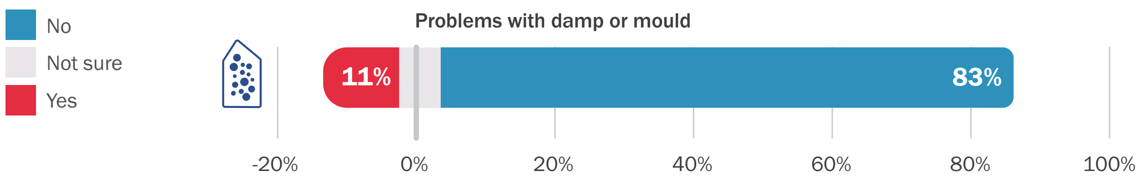


Figure 46: Reported issues with damp or mould

Confidence in controlling facilities

Overall, residents were confident in controlling their home facilities with 84% providing positive feedback, 12% feeling neutral and 4% indicating a negative experience (Figure 47).

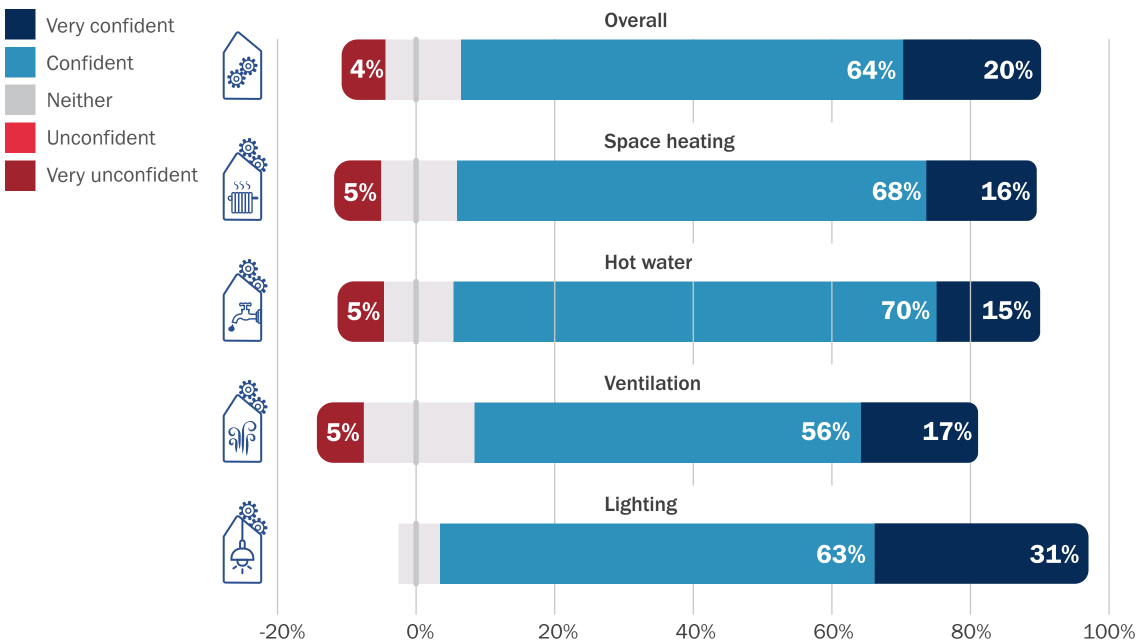


Figure 47: Resident confidence in controlling facilities

Perception of energy cost

The responses indicate a positive perception of energy costs (Figure 48). 47% viewed their energy costs as inexpensive or very inexpensive. 22% felt neutral, while 21% considered their energy costs expensive.

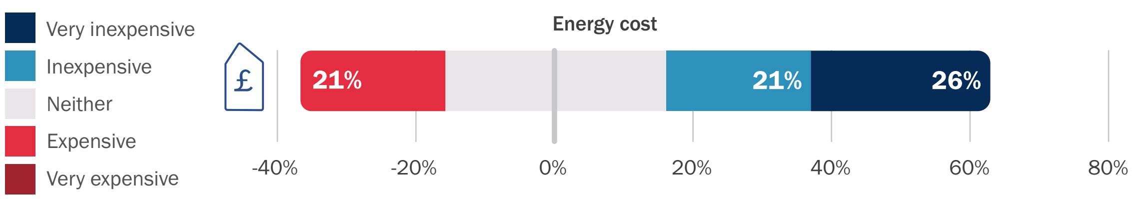


Figure 48: Perception of energy costs

Feedback on handover information

30% believed information provided was sufficient, while 69% of respondents felt they did not receive enough handover information (Figure 49). The percentage of positive responses increased after the first year indicating that improvements were made in how information was delivered over time.

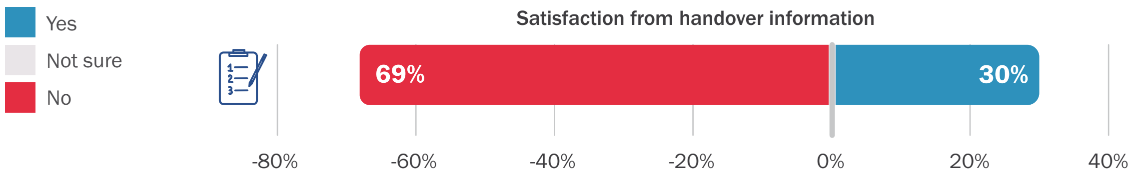


Figure 49: Feedback on handover information

When asked about their preferred ways of receiving handover information residents favoured two options (Figure 50).

- A website that they can refer to whenever needed.
- In-person visits, as these provide a more hands-on approach allowing residents to better understand how to use their systems in practice.

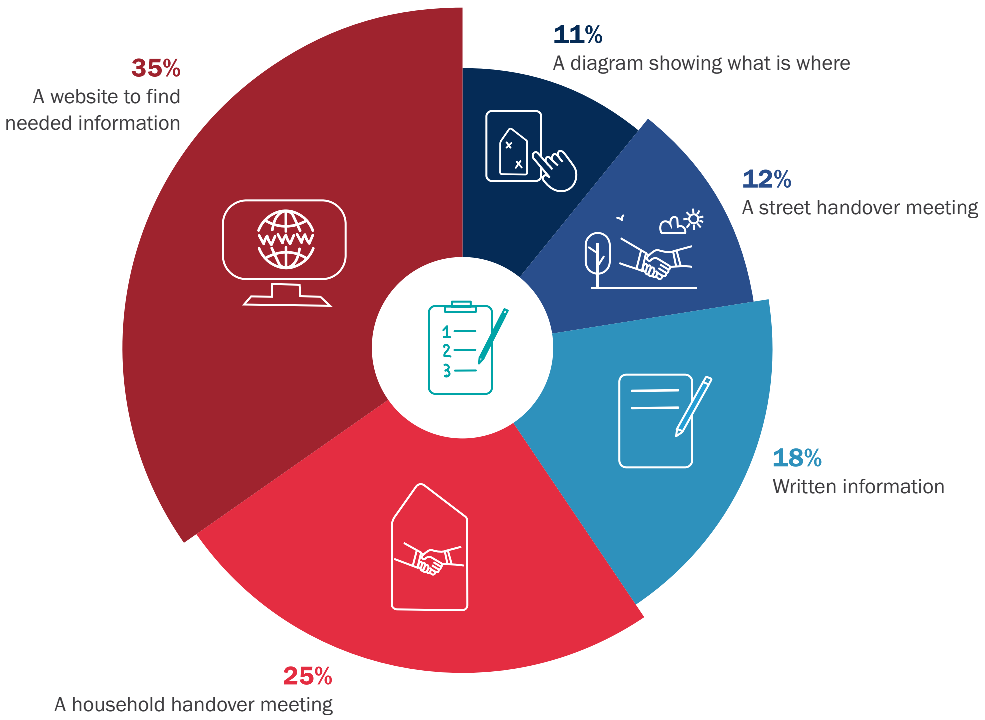


Figure 50: Preference of receiving handover information

5 Outcomes

Sixty five new build homes have been monitored and evaluated providing valuable insights into achieving low carbon emissions and energy bills.

Key outcomes of the monitoring and evaluation process are presented in Figure 51. Overall, the homes demonstrated excellent energy performance achieving in-use performance of less than 60 kWh/m²/year, outperforming comparable benchmarks and contributing to the UK Net-zero Carbon Buildings Standard [30]. Positive renewable integration and airtight, well-insulated envelopes. Renewables were positively integrated into the homes and the envelopes are well-insulated and airtight.

Residents reported good perceived levels of comfort and affordable energy bills, though information at handover should be improved to ensure higher levels of confidence in operating facilities. This improvement was actioned throughout the duration of the programme, and the benefits of the improvements were seen by the residents at site 3 and 4. For site 1, a handover booklet was prepared and shared with residents containing background information about the fabric and renewable technologies and how they worked together. The area housing officer visited a day or two after move-in day and provided an explanation of how everything worked. A follow-up visit was arranged a month later to check that the residents were settling in well and to repeat the information provided during the first visit. It was felt that too much information and time was spent on the technicalities of the equipment and how it worked rather than on the practicalities of using it on a day-to-day basis and how much interaction was required by the resident.

The process was revised with an electronic version of the booklet developed including links to product web-sites and “how-to” pages. Visits continued with an invitation for residents to request a revisit whenever needed. More emphasis was placed on the practical aspects of using the home and the systems rather than the mechanics.

There were issues with access to homes. SC accept that some residents will never want intrusion, however well-intentioned. The provision of accurate information is critical, once information has been provided it is very difficult to change the perceptions of residents.

Real-world monitoring and evaluation proved extremely valuable in identifying gaps between design and operation, supporting continuous improvement and more effective future delivery.

High overall energy performance

Average EUI was 58 kWh/m2/year, which was well below UK averages and in line with RIBA 2025 targets. Renewables generated 40 kWh/m2/year exporting more than 1/3 to the grid

Heating system underachieved

GSHP was stable with a COP of 2.6 indicating high use of hot water or/and inefficiencies. This still compares favourably with the ASHPs.

Significant contribution from renewables

BIPV panels and batteries supplied from 40% to 60% of energy needed without optimising export or variables tariffs

Comfort levels were high overall

Most residents were comfortable, especially in winter. Some experienced minor overheating in summer

Thermal envelope met U value design targets

U-values matched design expectations fulfilling the most demanding Standards (LETI, Passivhaus)

Indoor environmental quality maintained

CO2, temperature, and humidity stayed within acceptable ranges over 85-96% of the time

Airtightness achieved design targets

All homes achieved airtightness design target which is used for most new homes but is not as demanding as relevant Standards (LETI, Passivhaus)

Residents found bills acceptable

Around 80% described their energy bills as very inexpensive, inexpensive or average without benefitting from export or time variable tariffs

MVHR required fine-tuning

MVHR systems generally met design specs but sometimes needed recommissioning to perform optimally. Bypass setting may need adjustment to reduce summer overheating

Effective user support is essential

Challenges faced by some residents in adapting to new systems, such as heat pumps and MVHR, underscore the importance of improved onboarding and guidance

Insulation was effective but not perfect

Thermography confirmed good insulation overall, though common thermal bridging issues were observed at junctions and openings

Monitoring provides significant value

Both short and long-term monitoring identifies benefits as well as discrepancies between design and actual use, offering valuable insights for continuous system improvements and future development

Figure 51: Key outcomes from monitoring and evaluation of the Swansea Standard homes

5.1 Lessons learnt and recommendations

Many valuable lessons have been learnt whilst monitoring and evaluating the Swansea Standard homes. By sharing these lessons – both the successes and the challenges – associated with affordable new build low-carbon homes that combine reduced energy demand, renewable energy supply and energy storage, it is hoped that others will be inspired to invest in low-carbon housing.

The lessons learnt and associated recommendations to enhance the performance and occupant experience are split into two sections:

- Lessons learnt and recommendations that are specific to the 'Swansea Standard' homes but are likely to be relevant to other new build housing developments.
- Lessons learnt and recommendations that are more general to new build, affordable low carbon housing.

Lessons learnt and recommendations for future Swansea Standard homes

Building performance

- Replicate successful airtightness strategies – Lessons were learnt throughout the delivery of the four sites. By site 4 building fabric airtightness was improved significantly. The approach should be replicated in future projects to ensure optimal building envelope performance.
- Improve thermal envelope integrity – Thermographic inspections revealed that improvements could be made at:
    - Window and door frame sealings.
    - Junctions between floors/ceilings and external walls.
    - Loft hatch insulation.
    - Careful mounting of electrical appliances on walls and ceilings.
- Ensure robust MVHR commissioning and maintenance – The importance of proper MVHR commissioning and re-commissioning was highlighted by through monitoring. It is crucial to ensure design air flow rates are met and regularly maintained including routine filter replacements to guarantee optimal performance.
- Optimise GSHP hot water scheduling – Observations showed hot water production throughout the day, leading to higher-than-expected hot water delivery and energy bills. GSHP scheduling for DHW production should be optimised potentially prioritising heating during peak solar hours (12–3 pm) to maximise BIPV use.
- Refine PV and battery system sizing for different dwelling types – Flats consistently exported more excess electricity than houses. This suggests an opportunity to optimise BIPV system design by matching generation capacity with consumption patterns specific to each dwelling type or/and use time-variable tariffs.
- Address battery efficiency in flats – There were higher battery losses (up to 21%) in flats compared with houses and bungalows (around 16%). This may be due to less intensive battery use. Strategies could involve optimising battery usage/sizing for flats or educating occupants to use them more effectively to improve overall system efficiency during charge/discharge cycles.
- Investigate battery noise – On one site noise was perceived to be associated with battery storage system which requires further investigation to identify the cause and implement solutions.

Occupant comfort and engagement

- Address overheating in homes – Overheating was a concern especially during the non-heating season (11%–33% of the time) and occasionally during winter (3%–10% of the time). Strategies should be implemented to address overheating issues, through improved passive cooling measures or enhanced occupant guidance on effective window usage and ventilation control. Further investigation, through further occupant interviews could help understand the underlying causes of both overheating and underheating to determine if they are a personal preference or system performance.
- Manage indoor humidity and air movement – While relative humidity levels were generally acceptable, some properties experienced occasional dryness. This should be investigated and support for localised issues should be provided related to air movement and humidity to ensure that ventilation addresses any tendency towards dryness.
- Promote MVHR boost mode usage – To maintain optimal Indoor Air Quality and prevent CO_2 spikes, occupants could be advised to use the MVHR boost mode during gatherings or activities that generate higher CO_2 levels.
- Improve handover information effectiveness – Handover processes consistently received low satisfaction ratings. It was recommended to:
  - Deliver handover information at a more appropriate time rather than at the initial move-in period. Follow-up support should also be provided to improve occupant engagement and understanding of home systems.
  - Prioritise providing handover information through webpages and in-person meetings with household-level support, as these were preferred by residents over general group meetings or written guides.
- Simplify controls for DHW and ventilation – Residents expressed lower and variable confidence in controlling DHW and ventilation systems compared with heating or lighting. This indicates a need for clearer guidance, hands-on demonstrations and simplified control interfaces for these.
- Optimise hot water scheduling – Prioritise heating DHW during peak solar hours (12–3 pm) to maximise BIPV utilisation, moving away from the default 6 am–10 pm schedule that causes frequent cycling and increased electricity use.
- Immersion heater programming – Ensure the immersion heater is programmed for weekly heating to over 60ºC for anti-Legionella protection. This should be scheduled during peak solar hours to maximise the use of solar energy.
- Improve MVHR control – Install timed switches in wet rooms to give occupants the option to boost the MVHR system when needed to limit CO_2 spikes and odours.
- Enhance the handover process – Address the consistently low satisfaction with handover information by focusing on personalised in-home guidance and accessible webpages over longer time periods.
- Utilise time-variable tariffs – To further reduce energy costs and maximise self-consumption, encourage occupants to align battery charging and energy use with time-variable tariffs.

5.2 Recommendations for delivering successful new build, affordable low-carbon housing

Creating affordable low-carbon homes that work for people takes effort from everyone – residents, landlords, industry and government. It is not just about new technology or building design, but about how we communicate, support one another and keep learning and developing. The following recommendations offer practical guidance to make new build, affordable low carbon homes more comfortable, efficient and successful.

Recommendations for all

1. Communicate clearly, collaborate often

Open communication between residents, landlords, industry and government ensures new technologies are used effectively and homes perform as designed. Improvements were made to handover activities as the programme progressed, residents confirmed that better level of information was provided.

2. Monitor and learn

Measuring real-life performance should be a priority, as monitoring reveals what works, helps identify issues early and supports better decision-making for future developments. This is evident through the adjustments initiated by SC in response to monitoring findings.

3. People make the difference

While design is important, the way people live and interact with their homes is critical influencing comfort, efficiency and how well the home performs. This is shown by the variability of the energy use despite identical construction and technology.

Recommendations for residents

1. Ask questions early and often

If something is not working or causes confusion, residents should feel confident to engage. Early support prevents small issues from becoming big ones. This was observed in several homes especially in the first site where some innovative systems needed to be reconfigured to ensure comfort and low energy use.

2. Learn about their home and its systems

Residents should take time to understand their home and how to use the systems installed e.g. heat pumps, ventilation or smart controls. This can make everyday life more comfortable and help lower energy costs. This was evident throughout the interviews, residents who were more engaged were able to adjust their system to provide better comfort and energy use.

Recommendations for social landlords

1. Keep knowledge in the team

It is important to share knowledge and store information about homes and their systems so that the whole team can access information. Design, construction site and maintenance teams should log irregularities and reflect on learnings together. This helps ensure smoother maintenance and provide better support for residents and future projects.

2. Support residents long-term

Offering help frequently after handover can boost confidence, increase satisfaction and keep homes running smoothly over time. Having 'a person to talk to' was identified as being very important throughout the interviews helping to optimise comfort and energy use as residents felt supported.

3. Service and monitor regularly

Scheduling regular checks for heating, ventilation, solar panels and batteries, along with using monitoring can help identify issues early and enable systems to work well. For example, energy meters on consumer units or on control panels allowed for informed adjustments and maintenance actions.

Recommendations for industry

1. Design for real people

Focusing on user-friendly controls, simple interfaces and clear layouts can make homes easier to manage and better suited to everyday life. For example, the heating system control panel was easy to use when explained and allowed residents to enhance comfort.

2. Get commissioning right

Thoroughly testing all systems before handover can prevent issues that might impact on comfort and performance of other systems such as heating helping to build trust. For example, problematic MVHR commissioning created drafts and discomfort in homes on the first site. This was improved throughout and by site 4 MVHR commissioning was correct, the value of taking time could be seen and a well-balanced comfortable environment was created.

3. Simplify guidance and technologies

Using consistent standards and making technologies easier to use — with clear guidance and intuitive systems — can lead to better results and encourage wider adoption. For example, residents and social landlords could not make use of time-of use tariffs preventing getting the best out of BIPVs and batteries. Industry and utility companies could not assist by standardising or explaining actions needed to lower bills.

Recommendations for Government

1. Invest in skills and training

Providing training in low-carbon techniques, such as airtightness and MVHR testing and heat pump installation, can help the construction sector deliver high-quality homes with confidence.

2. Support what works

Support the uptake of low-carbon homes with financial incentives and real-world data can help shape policies that are both socially just and effective.

3. Educate and empower residents

Provide clear and easy-to-understand education on low-carbon living which can help everyone get the most from their homes.

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About the project

This report presents the monitoring and evaluation of 65 new build affordable low-carbon homes designed and built by Swansea Council. The monitoring and evaluation was carried out by researchers at the Centre for a Low Carbon Built Environment at the Welsh School of Architecture, Cardiff University.

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